WASTEWATER QUALITY INDEX FOR SEWAGE FARMING

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CERTIFICATE

Certified that the work presented in this thesis ntitled 'Wastewater Quality Index for Sewage Farming' by apt. Ashok Kumar Madan has been carried out under my upervision and it has not been submitted elsewhere for a egree.

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ABSTRACT

Provision of potable running water for domestic use invariably produces wastewater. While sufficient care and attention is paid to produce water of standard quality, not much importance is given to treatment and disposal of wastewater. It is the most neglected part in the planning of public health practices in our country. Prevalent is the practice of sewage farming in almost all towns and cities having sewerage system. Sewage farming prompted by economic gains in crop production due to nutritional quality of wastewater and propelled by the availability of water round the year, results in propagation of enteric diseases in the consumer community, adversely affects the farm workers and has deleterious effects on the crops and soil of the place, if the sewage applied is untreated.

Keeping these factors in view, a study is undertaken to find out the present practices of sewage management in cities where sewage is used for farming. The data collected from these cities include information on water resources and supply, status of sewerage system, methodology of treatment, if any, wastewater characteristics, status of sewage farming and connected health aspects.

A wastewater quality index specifically for the use of sewage for farming is derived based on discriminant analysis (a multivariate statistical technique). From the data collected on wastewater characteristics and information available in literature, different pollutant parameters affecting

different aspects of sewage farming, viz., health, crops and soils, provided the basis for formulating separate indices for all these aspects. The results of all such indices are then combined into an accumulative index indicating the overall suitability or otherwise of any wastewater for farming.

Using this index the wastewaters from the cities (from where data are collected) are analysed. Wherever the quality of wastewater is found not matching the index, based on the available technological information, the type and degree of treatment required to meet the index requirements, is suggested.

This index, which can be used for any place based on the availability of required data, may enable better identification of factors affecting different aspects of sewage farming and prove to be a valuable tool for planners in the field of environmental sanitation.

1. INTRODUCTION

A convenient supply of safe water and the sanitary disposal of human wastes are essential, although not the only, ingredients of a healthy productive life. In industrialized countries the standard solution for sanitary disposal of human excreta is waterborne sewerage. Many of the developing countries face the problem of high expectations of achieving public health coupled with limited resources to plan and achieve similar conveniences and standards. Most of the decision makers try to follow the same path of modernization as that of the developed countries. Even though a little over 30% of the urban population in India is served by the sewerage system, more than half of the quantity of sewage is disposed off on land, without any treatment.(1)

Most of the civic bodies find it difficult to allot funds for any type of treatment because of the priorities and demands on their financial resources by other sectors. In majority of the cities and towns the wastewater is used for irrigation and vegetable farming. Motivated by the availability of water round the year, realising the nutritive and fertilizing value of sewage and the economic benefits associated with the sale of the product, most of the farmers use the untreated sewage for farming. It would be impracticable to expect a farmer not to use a water available at no cost irrespective of health effects on consumers of his produce.

Use of untreated sewage for sewage farming is not only deleterious to the health of consumers, but is a major health

hazard to the farm workers. It also adversely affects the crops and the soil in the long run. Thus planners in the field of environmental engineering are faced with a conflicting and complex problem that has no simple solution. No public health engineer can condone the use of raw sewage for production of a contaminated produce; no amount of legislation can prevent a farmer from using the raw wastewater for irrigation, if it is available. Sewage contains so many micro and macro nutrients that can be best recovered by plants grown in the sewage farms. Recent emphasis in the field of environmental management is recovery of resources and energy and reuse of materials wherever possible.

Hence an approach to such a problem necessarily needs a closer analysis of all the pros and cons and arrive at an optimal solution. However, certain boundary conditions should be laid down before an attempt is made in this give and take solution. It is felt that a realistic evaluation should be made on the use of raw wastewater for irrigation purposes. The factors that are contradictory for a safe and healthy environment should be seriously considered and a method of elimination of such factors should be sought.

A method involving a certain degree of treatment, requires a measure of the effect of wastewater on all aspects of farming viz. health of consumers and farm workers, crop yields and soil conditions. Such a method of assessment on a quantitative basis is not available. Quantification of information is extremely difficult but unfortunately essential for

any rational approach to solutions. This requires to quantify all aspects according to certain priority and come out with a comprehensive factor which would indicate whether domestic wastewater from a particular community is suitable for sewage farming or not. Based on this, one could search, evaluate and select the type and degree of pretreatment needed before its utilization.

Problems closely associated with socio-economic conditions are tackeled by quantifying certain parameters by giving weightages and ratings. In the present context, one faces factors that are subjective as well as scientific. Technology is available to yield any quality of effluent from any quality of raw waste or water, the controlling factor being the economics of treatment. In the field of agriculture considerable amount of information is available regarding the influence of various constituents in the irrigation water or waste on the growth and fertility of various field crops, vegetables and fodder crops. Different soils support different types of plant life and react varyingly to the bio-physico-chemical constituents of irrigation water/waste. Extensive work has been done and recorded regarding the types of diseases, transmitted to the workers in the sewage farm and to the community at large utilising the produce.

An attempt is made in the present study of evolve an index to give relevant information about wastewater quality for the purpose of treatment required prior to its use for farming. To obtain practical and meaningful information it

is felt that data should be collected from selected representative cities where sewage is used for farming purposes.

The aim and scope can be listed as follows:

Aim

1. To collect data from various cities/towns representing different parts of country where sewage farming is practised.
2. To develop an index that classifies a given wastewater as suitable or unsuitable for sewage farming specifically indicating its suitability or otherwise for the type of soil, type of crop, health of farm workers, and health of human and animal consumers of farm produce.
3. To suggest the type and degree of treatment required, if any, for the given wastewater to be reclassified into the 'suitable' group.

Scope

1. This study is specific that the wastewater quality is to be assessed for sewage farming and not for any other type of disposal.
2. The parameters of wastewater evaluated pertain strictly to domestic sewage.
3. The method of irrigation has been restricted to Broad Irrigation only.
4. Soils are broadly grouped into four categories viz., sandy, sandyloam, clayey-loam and clayey.
5. On the basis of their general tolerance to salt contents, the crops have been grouped as Fruit and Vegetable, Field and Fodder crops.

6. The health aspects are restricted to that of sewage farm workers, the reported contamination of vegetable and field crops affecting humans and the deleterious effects on animals which consume sewage irrigated fodder.

These and other general aspects are presented and discussed in the following chapters of this study.

2. LITERATURE REVIEW

2.1. Background and History:

The concept of land application of wastewater certainly is not new to the field of sanitary engineering. Evidence of such systems in western civilization extends back as far as ancient Athens.[2] Sewage farming was practised in Europe as early as 1559. The practice became fairly widespread in England, Australia, Germany, France and U.S. during the late 1800's.[3,4] During the middle of last century Liebig recommended land treatment as the best method of disposal.[5] It was about the same time when in England the First Commission on Sewage Disposal[5] also observed: "The right way to dispose off town sewage is to apply it continuously to land, and it is only by such application that the pollution of rivers can be avoided". In 1868, the Second Royal Commission while comparing the efficiencies of three methods of treatment then in vogue, viz., chemical precipitation, filtration and irrigation recorded that land treatment was more effective in removing the organic matter in solution and suspension than chemical precipitation. In 1881, Pullman, Illinois, U.S., which had a separate sewage system, became the first municipality to use a sewage farm for sewage disposal.[4]

Besides that of sewage disposal, the other major benefit which mainly attracted people towards this system was recovery of the valuable nutrients. Among the crops grown on sewage farms were potatoes, wheat, oats, barley, ›ts, while Italian rye grass was quite popular.[6]

2.2. Decline/Revival of Sewage Farming:

Inspite of this popularity, however, sewage farming as a technique of sewage disposal started loosing favour in the 20th century. This was largely due to the fact that growth of cities towards their suburbs rendered these farms inadequate. With progressive industrialization, the land within close access became more expensive and planners started recommending other methods of sewage disposal. These were compact, occupied less space and could be operated mechanically. When the reverse trend in the popularity of sewage farming started, the limitations of the process received great publicity. The planners in the U.S., argued that sewage was really valuable only in a theoretical sense, and the cost of reclaiming the fertilizing elements far outweighed their actual value. The public health engineers pointed out that these farms were the source of odour and flies, while the crops grown posed the threat of disease transmission. Because of these factors, sewage farming was increasingly abandoned in the Northeast and Middle Western states.(5) In place of land disposal cities constructed, though relying on the same agencies of aeration and oxidation, more technology-intensive systems such as trickling filters and activated sludge facilities which were regarded as "modern".

However, recently, the increasing awareness of the need for conservation of natural resources and refusal of different water bodies to assimilate even the highly treated effluents, have forced the revival of sewage irrigation which had suffered

a setback after the emergence of modern methods of sewage treatment.

2.3. Lessons from the History:

The history of sewage farming offers various lessons to the policy makers dealing with wastewater disposal today. Firstly, the "out of sight, out of mind" approach to waste disposal ultimately means higher and not lower costs. Sewage farming offers an "ultimate sink", any domestic waste requires, in a productive way. The cost accounting for technology-intensive systems must be based upon a cost/benefit calculus considering the long term environmental impacts. Those involved in sewage farming today are also required to closely monitor the system to prevent both health hazards and the creation of nuisance. These are especially critical in terms of securing public support. Finally, it is concluded that sewage farming is more appropriate where land and labour both are available and inappropriate where both are critically needed for other purposes.

2.4. Status of Sewage Farming in India:

Sewage either raw or partially treated is being used in India for farm irrigation since time immemorial. The system had been adopted by the individual farmers since it gave better yield of crops. Various municipalities adopted sewage farming primarily as an effective and cheap method of sewage disposal. Raising of crops and obtaining revenue was secondary for them.

Till 1971 there were 132 sewage farms in the country covering approximately 12,000 hectares (30,000 acres) and utilizing 1 million cubic metres (223 million gallons) of sewage per day.[7] Though the amount of sewage produced in the country has since gone up considerably, the number of sewage farms did not increase much due to the apparent bad points of the system. Most of the municipalities started, disposing of their sewage into neighbouring water bodies. A recent report of Central Board for the Prevention and Control of Water Pollution[8] places the amount of sewage production at 9000 million litres everyday and this quantity of sewage is generated in about 142 class I cities. The report also adds that only 37% of this liquid waste is receiving some form of treatment and the rest is emptied into the water bodies.

The data collected by NEERI-Nagpur[9] indicates that at certain places, where sewage farms are existing, though the volume of sewage has increased considerably, the acreage covered has not increased accordingly. This has resulted into the development of septic conditions around the farms and overall unhygenic conditions. The state of various sewage farms in the country was assessed by Shende et.al.[9] and Mishra[41] and is presented in Tables 2.1 and 2.2 respectively. Most of these farms are getting partially treated or raw sewage. Mohan Rao[1] observed that a majority of sewage farms are neither managed properly nor do they provide any health protection to their workers.

Table 2.1

Application rates of sewage effluents and contribution of nitrogen at some typical sewage farms in India[9]

Location of farm	Area in hectares	Volume of sewage used (mld)	Form of sewage used	Average (assured) nitrogen concentration (mg/l)	Average application rate (m^3/d/ha)	Average daily contribution of nitrogen (kg/d/hectare)	Average annual (3 days) contribution of nitrogen (kg/ha/ann
1. Ahmedabad	890.3	299.9	raw	60	336.8	20.208	6062
2. Amritsar	1214.1	54.5	raw diluted	60	44.9	2.694	808
3. Bikaner	40.4	13.6	raw	60	336.8	20.208	6062
4. Bhilai	607.0	36.3	SPE	25	59.9	1.497	449
5. Delhi	1214.1	227.2	treated (primary & secondary)	30	187.1	5.613	1684
6. Gwaliar	202.3	11.3	raw	60	56.1	3.366	1010
7. Hyderabad	607.0	95.4	raw diluted (primary treatment	40	157.2	6.288	1886
8. Jamshedpur	113.3	9.1	treated (secondary)	25	80.2	2.005	601
9. Kanpur	1416.4	31.8	raw diluted	60	22.4	1.344	403
10. Madras	133.5	6.8	raw	60	51.0	3.060	918
11. Madurai	76.9	13.6	raw	60	177.3	10.638	3191
12. Trivendram	37.2	8.6	raw diluted	60	231.9	13.914	4174

Note: Original figures in gallons and acres have been converted into litres/m^3 and hectares respectively.

SPE - Stabilization Pond Effluent.

Table 2.2

Quantity of sewage effluent applied in different sewage farms(41)

Name of farm	Nature of soil	Quantity of sewage (in mill gal/day)	Type of sewage	Crop area (acre)	Dosage applied (gal/acre/day)	Dilutio[n] water
Hyderabad	Loam Clay loam	33.94	Primary treated diluted	3,200	3,800	Available
Madurai	Sandy and sandy loam	3.00	Raw	180	16,750	Not availa[ble]
Kanpur	Alluvial loam	9.40	Raw diluted	3,200	3,000	Available
Allahabad	Alluvial loam	3.13	Raw	313	10,000	-
Lucknow	Loams	7.24	Raw diluted	720	10,050	Available
Ahmedabad	Sandy and sandy loams	40.00	Raw diluted	2,460	15,300	Textile effluent
Poona	Clay and clay loams	10.28	Raw diluted	650	16,000	Available
Delhi	Loams	36.66	Raw and treated	3,800	9,647	Not availa[ble]

2.5. Need for Development of Sewage Farming:

In a country where the rivers are in spate for 3 months and practically dry for 3 to 6 months, utilization of sewage effluents on land is the best method of its disposal.

Sewage farming is good for a country that is deficient in basic foods and chemical fertilizers. India is one of the few countries where a substantial percentage of the total land area is under cultivation, yet the yield per acre in India is about the lowest in the world.(10) It is due to the fact that our soils are not getting enough suitable nutrients to replenish the drain on their resources. Cultivated plants require for their growth a good mellow-top soil containing humus and moisture, a certain amount of nutrients, sunlight and air. The deficiency of any of these factors bears on the output of the crop. Soil usually contains nearly a sufficient amount of the different elements, with the exception of nitrogen, phosphorus, potassium and lime. It is these and some trace elements that are chiefly required for the production of healthy crops.(11) If sewage effluent is capable of providing all these elements in a ready to serve state, then it has, indeed, a claim to agricultural priority. Sewage as applied to land has a four fold value, for it contains the major fertilizing elements, the micro-nutrients, that is, the trace elements, organic matter and its major constituent - water.

2.5.1. Sewage - A Source of Nutrients:

The nutrient value of wastewater is considerable. Total nitrogen ranges from 25 to 70 mg/l, phosphate from 7 to 20 mg/l and potash from 12 to 30 mg/l. It is estimated that

the Indian population of 638 millions (1978) contributes annually about 2.5 million tonnes of nitrogen, 0.9 million tonnes of P_2O_5 and 0.8 million tonnes of K_2O, besides other macro and micro nutrients and decompostable organic matter.[9] It will be interesting to note that these figures are greater than the production of chemical fertilizers in India during 1977-1978 which stood at 2 million tonnes of nitrogen, and 0.67 million tonnes of P_2O_5.[9]

Commercial fertilizers supply N, P, and K but lack the soil conditioners composed of decayed organic matter. In the absence of organic matter these fertilizers may not affect the growth of crops. In such case they may do more harm than good.[12]

However, there are two opposite views regarding the efficacy of sewage in stepping up of agricultural production. It is apprehended by some[9] that sewage contains excessive amounts of fertilizing ingredients, especially nitrogen and that such excessive supplies of nitrogen may result in more leafy growth and less food value. They consider that the dilution of sewage with larger quantities of water is necessary. Quite the contrary view is ocassionally expressed indicating that the success of sewage irrigation depends on "the water value of the sewage rather than on its fertilizing constituents",[2] but this view is not widely shared. Experience all over the world shows that various farms have, and even now, without using any additional fertilizers, been utilizing sewage and raising high yielding crops.

Day et.al.[13] found that wheat grain grown with waste-water contained more protein than wheat grain produced with well water and fertilized with equivalent amounts of N, P and K. A recent study conducted at NEERI-Nagpur[14] also substantiates their claim by achieving additional yields with the use of oxidation pond effluent alone when compared with those grown with well water added with recommended doses of N, P and K.

2.5.2. Sewage - A Source of Water:

In arid and semi-arid regions where shortage of water becomes a limiting factor in agriculture the sewage serves as an additional and readily available source of water. As observed by Heukelekian[15] that in Israel it is not the lack of land that controls further expansion of agriculture, but it is the limitation of water for irrigation. He thus recommends the use of sewage for irrigation which will be sufficient to bring an additional 50,000 acres under cultivation.

2.5.3. Sewage Farming - A Mode of Disposal:

Lastly, the use of sewage for irrigation provides a comparatively economical method of disposal of waste which a community must get rid of for healthy living. Thus the two objectives of adequate disposal and utilization of sewage for producing food can be achieved simultaneously by adopting sewage farming.

2.6. Suitability of Sewage for Irrigation:

Sewage, of course, is rich in practically all the elements required for plant nutrition, the basic inherent

feature of sewage irrigation which differentiates it from ordinary irrigation is that sewage is not clean water but is 'soiled' water. It is highly contaminated with pathogenic organism and contains considerable amount of suspended and dissolved impurities which may affect the soil and crops adversely.

2.6.1. Pathogenic Contamination:

Many micro-organisms pathogenic to either humans or animals, or both, may be carried in municipal wastewater. Dunlop[16] found that pathogens carried in municipal waste-water include various viruses, bacteria, protozoa and helminths. The health hazards associated with these organisms include diseases like, bacillary and amoebic dysentry, salmonellosis, gastro-enteritis, typhoid and para-typhoid fevers, cholera and infectious hepatitus and different worm infestations.[17]

These hazards are further divided in two categories; (1) the occupational hazards to the farm-workers; and (2) transmission of these disease through agricultural products to the humans and animals who consume them.

Those who work in the sewage farms are most exposed to the infections while carrying out agricultural activities. Sinnecker[18] found a great rate of parasitic infections amongst sewage farm workers while comparing them with urban sewer workers. Patel,[7] at Baroda, and Kabir[7] at Madurai, where raw sewage is used for irrigation, evaluated the health status. Their studies showed high incidence of helminthic infection among the sewage farm population as compared to that

of controlled group. A thorough clinical examination for gastro-entestinal, anaemia, respiratory and skin diseases was conducted by CPHERI in 1971[7] at three different farms. It revealed that a higher percentage of sewage farm-workers was suffering from all these diseases as compared to the farming population, in general.

Various diseases caused by pathogens through sewage farm products, have been reported amongst the human population. Various typhoid epidemics in Germany have been traced to contamination of crops irrigated with sewage. These epidemics have been reported in Frankfurt, Vienna and Luneberg.[18] Heavy worm infestations caused by eating sewage polluted vegetables have also been reported under the same studies. Hookworm disease amongst the human consumers of the sewage farm vegetables has also been reported in India.[19]

The presence of Taenia Saginata, Salmonella and tubercle bacilli, responsible to cause, beef tape worm, salmonellosis and tuberculosis, respectively, amongst the animals, has been reported in the domestic wastewater.[20] In Poland a survey of animals pasturing on municipal sewage farms revealed that 21% of the cows and all of the sheep were infected with animal parasites.[21] In Arizona heavy beef-tape worm infection occurred in cattle pasturing on sewage farms.[22]

The degree of risk of infection from sewage borne pathogens depends on factors such as (1) occurrence and survival of pathogens in soil and on crops; (2) minimal infectious dose required to cause infection and (3) extractive effieiency of the treatment systems.

(1) Occurrence and survival of pathogens in soil and on crops: It would appear from the review of literature carried out by Rudolfs[17] that crops growing in infected soil can become contaminated and these pathogens may survive for periods of a few days to several weeks or more in the soil. However, it is noted from another study[23] that pathogens are seldom detected on farm produce unless they are grossly contaminated with sewage. Whether or not the pathogens become attached to the surface of the crops depends upon the method of sewage application and the type of crop. Crops grown on or near the ground are almost certain to become contaminated.[20]

(a) Virus: The work of Shuval[24] indicates that domestic sewage carries from 1-100 enteric virus/ml. These viruses include polio virus, echo virus and coxsackie virus. The survival of various viruses on crops is reported to be upto two months and on soils upto six months.[48]

(b) Coliform Bacteria: Norman[25] reported that leafy vegetables had higher coliform counts than smooth ones. Studies made in Berlin[26] on clover, spray-irrigated with settled sewage, showed that all the leaves were affected with coliform bacteria. Heavy rainfalls did not wash away the bacteria but increased the densities by secondary infection.

(c) Salmonella: Muller[27] has reported that two places near Hamburg, Germany, where sprinkler irrigation was used Salmonella organisms were isolated 40 days after sprinkling on potatoes, 10 days on carrots and after a

period of 5 days on cabbage. Rudolphs[17] found that Salmonella and Shigella organisms did not survive for more than 7 days on irrigated vegetables.

(d) Amoeba: While reporting on the survival of amoeba cysts on the crops Rudolphs[17] stated that these cysts are extremely sensitive to dessication and die off within 3 days on contaminated vegetables. The survival of amoeba cysts in water is related to temperature and the amount of organisms present.[28] Their survival on soil is reported to be for 2 to 10 days.[20]

(e) Helminths: Survival of Ascaris eggs was also studied by Rudolphs.[17] Ascaris is one of the more resistant germs of the helminth parasites and survives for long periods in water and sewage. Its eggs die off rapidly in soil exposed to sun but are extremely resistant on vegetables where they have access to moisture. Eggs are found to be less numerous on furrow irrigated land than on sprinkler irrigated land. Ascaris ova are reported to survive for two years in irrigated soil and one month on crops.[28]

(f) Beef Tape Worm (Taenia Saginatta): This helminth circulates between men and cattle and infection only continues when cattle eat Taenia eggs that humans have excreted. Taenia ova are very hardy and can survive well outside the host. They may survive in soil or pasture for over six months.

The literature review on the survival of pathogens on crops clearly brings out the fact that the survival of most of them (except perhaps protozoa) is quite sufficient to be transported to the users and infect those who handle, process, cook or eat the crop.

The chances of contamination of crops can be reduced by using furrow or Broad-irrigation instead of sprinklers, by stopping irrigation as early as possible before harvest begins, and by educating farm workers on sanitation practices for harvest.[23]

(2) Minimal infectious dose required: To fix up limitations for various pathogens passing on to the consumers through the products from sewage farming, the knowledge of minimal dose of such pathogens required to cause infection will be of great help.

While the minimal infective dose for some diseases may be a single organism or very few, the doses required in most bacterial infections are much higher. Data on this are very hard to acquire, since they involve administering a known dose of a pathogen to a volunteer. For viruses there is evidence of low infective doses in experiments, and in human populations for some but not all virus infections.[20] Among the helminths a single egg or larva can infect if ingested, even though a high proportion of worms can fail to develop to maturity, especially where immunity is present.

Shuval[29] on reviewing the literature on the subject concludes that ingestion of very low levels of typhoid bacilli,

enteroviruses, cholera organisms and protozoan or helminthic pathogens is sufficient to cause infection. It, therefore, becomes essential to achieve very high removals of enteric pathogens when sewage use is associated with human consumption of crops or body contact.

(3) Pathogen removal efficiency of treatment systems: The efficiency of available treatment systems in considerable removal of various pathogens is different and to some extent debatable. Substantial literature on the subject reviewed previously has been compiled recently by some workers.[20,24,30,31]

Feachem et.al.[20] while summarizing their study state, "imposition of stringent quality standards on effluents (less than 1001 fecal coliforms and fecal streptoccoi per 100 milli litres) restricts the range of treatment technologies considerably. Fortunately, waste stabilisation ponds are both able to meet these standards and are a low-cost and appropriate form of waste treatment in hot climates".

Shuval[24] while concluding the literature survey carried out by him states that it is possible by optimal combination of wastewater treatment and chemical disinfection to achieve coliform counts lower than 100/100 ml, but, not the effective removal of viruses. Ozone, however, is most effective virocidal agent and 99% kill of polio-virus can be achieved by using ozone under controlled conditions.

Sepp[30] concluded that the primary sedimentation of sewage for two hours will remove most of the *Ascaris* eggs. Amoeba cysts could be removed by chemical precipitation

and intermittent sand filtration. Secondary sand filtration and underdrained land filtration were 100% effective in removing the eggs and cysts of animal parasites. 99% removals in coliform and 80% in <u>Ascaris</u> ova were attained when primary treated effluent was chlorinated. 90% removal of viruses could be achieved by activated sludge treatment.

Another review of literature[31] reveals that secondary sewage effluent can be chlorinated to reduce the fecal coliform bacteria below 1000/100 ml. Viruses, however, may survive chlorination. Filtration through soil was found to be another effective way to remove fecal bacteria.

Vegetable contamination studies performed by Rudolphs[33] indicated that washing vegetables with plain water or with various detergents was quite ineffective in removing bacteria. Rinsing with chlorine proved unreliable, although it gave better results. The only effective means of cleansing contaminated vegetables was found to be soaking the vegetables in water at 60°C for five minutes, which does not seem to be a practical solution.

2.6.2. Suspended Impurities:

Suspended impurities in sewage correspond mainly to the silt contents. Their effect on the irrigated soil depends upon the characteristics of the soil. In very sandy soils, with low content of nutrients, the accumulation of silt has a directly beneficial value. But in many other cases it may adversely affect by lowering the permeability of soils. The colloidal particles' deposition on the soil surface may

result into crust formation which inhibits water-infiltration and seedling emergence. This alteration of the mechanical structure of the soil can bring about inadequate aeration which is the fundamental cause of sewage sickness.[32] This also results in to the formation of gases such as methane and hydrogen sulphide. In surface irrigation, suspended solids can interfere with the flow of water in conveyance systems and reduce their carrying capacity. In sprinkler irrigation the suspended mineral solids may cause undue wear on pumps and sprinkler nozzles.

2.6.3. <u>Dissolved Impurities</u>:

The dissolved constituents of sewage mainly represent its salt contents. They have a dual effect on the irrigation system: (i) direct effect on the plants either due to the development of high osmotic conditions or the presence of certain phytotoxic constituents; (ii) indirect effect on the growth of plant through their influence on soil.

In general, plants are more susceptible to injury from dissolved constituents during germination and early growth than at maturity.[31] Certain elements may not be harmful directly for the crop production but may accumulate in crops to levels that may be harmful to the consumers. The studies of Stone and Merrell[34] indicate that sewage is normally quite satisfactory for irrigation from the standpoint of mineral content provided excess sea water infiltrations are excluded.

Excess of calcium and magnesium make the water hard, which keeps the soil open and permeable. Excess of sodium,

on the other hand, makes soft water, which produces poor tilth, low permeability and alkaline conditions in the soil. Wilcox[35] summarized the results of his study as: "Hard water makes soft land and soft water makes hard land". The percentage of cation exchange capacity taken up by sodium is called Exchangeable Sodium Percentage (ESP). Coarse textured soils can tolerate a higher ESP than fine textured soils.[31] To estimate the degree to which sodium will be adsorbed by any soil, from water, another measure proposed by U.S. Agriculture Department[36] is Sodium Adsorption Ratio (SAR),

$$SAR = \frac{Na^{+}}{\sqrt{\frac{(Ca^{++} + Mg^{++})}{2}}} \quad \text{(All expressed in me/l).}$$

The effect of high salinity on the osmotic pressure of soil solution has been found to be one of the most important quality considerations for crop growth. The concentration of salts generally expressed as TDS on weight basis, i.e. as ppm, ignores a major fact that a particular salt may have a much greater effect than the others present in equal quantities. A good agreement has been found to exist between the quality of salt present, conductance and osmotic pressure of the solution.[36] This has resulted into the use of Electrical Conductivity (EC) expressed in micromhos/cm and has been accepted as the standard procedure for evaluating the salt content. Effect of different values of EC on different soils, depending upon their permeability, is well documented.[35,36] The ratio of TDS in ppm to EC in micromhos/cm at 25°C is about 0.64.[37]

Chlorides in excess may prove toxic to certain fruit crops. Silty-clay loams accumulate more chlorides in a given time than sandy loams and sands.[38]

High bicarbonate water may induce iron chlorisis by making iron unavailable to plants. In waters containing high concentrations of bicarbonate ions, there is a tendency for calcium and magnesium to precipitate as carbonates as the soil solution becomes more concentrated, thereby increasing the relative proportion of sodium.[35] Certain Indian studies, however, show that use of water with high concentration of bicarbonates is not harmful.[39,40]

2.6.3.1. Concentration Limits:

The effect of concentration of different constituents is governed by many factors: permeability of soil, quantity of sewage applied, method of irrigation, climatic conditions, crops species and various other agricultural operations. Permeability of soil, however, plays a major role. Saline conditions will develop even with good irrigation water in a poorly drained soil and conversely, fairly saline waters may be used on well drained soils. Pillai[49] finds the soil conditions at Madurai sewage farm much better than the other untreated sewage irrigated farms, mainly, because of the adequate drainage provided there by means of under drains.

In spite of the dependence on all these factors certain critical concentrations of various constituents beyond which they become inhibitory for agriculture, have been suggested previously.

Different values of total dissolved solids have been suggested by many workers.[35,37,41] Water containing upto 1000 mg/l has been found to be suitable for growing all types of crops on well drained soils, whereas, water with more than 3000 mg/l of salt concentration has been classified as unsuitable even when good drainage exists.[41] Camp[37] points out that only salt sensitive crops may be adversely affected with conductivity values from 250 to 750 micromhos/cm depending upon leaching and drainage conditions; under inadequate drainage condition waters in the range of 750 to 2250 micromhos/cm may also create saline conditions. To use waters with conductivity of 2250, he recommends the SAR value to be less than 4 and with conductivity value of 750, SAR could go upto 6.

The U.S. Salinity Lab has proposed a diagram for classifying irrigation waters based on EC and SAR[36] which is presented here as Figure 2.1. Mahida[5] has classified the waters based on SAR values as given below:

SAR	Water Class
<10	Excellent
10 - 18	Good
18 - 26	Fair
>26	Poor

In one of the studies water having SAR values of 4 to 8 has been found to injure sodium sensitive plants.[31]

For sensitive food crops the maximum permissible limits of chlorides in soil solution range from 10 to 50 meq/l.

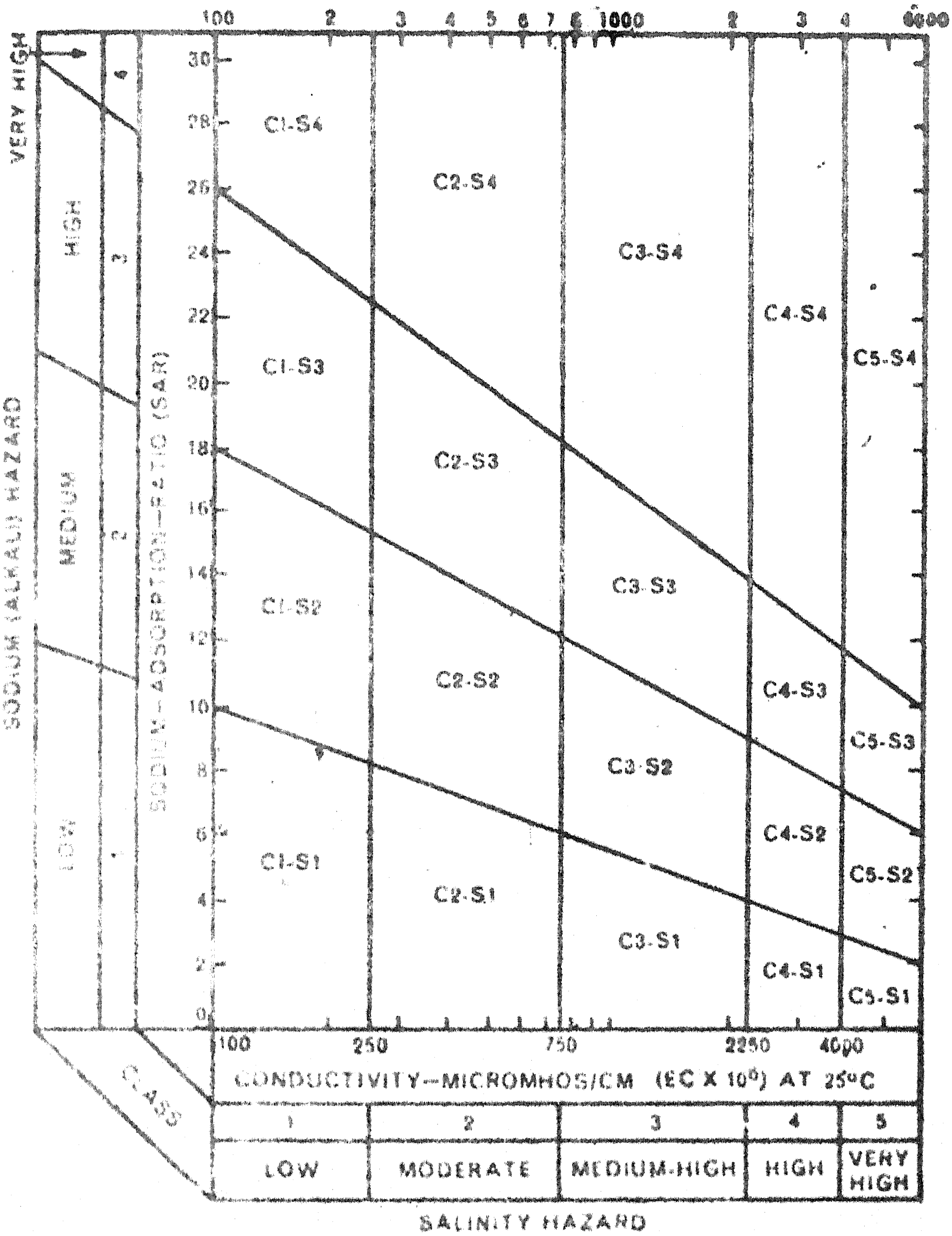

Figure [illegible]. Diagram for determining the quality rating of an irrigation water from its sodium adsorption ratio and electrical conductivity.(5)

Limits have been proposed for irrigation water in general as 20 meq/l. Maximum permissible limits fixed as per ISI Standards[42] for industrial waste are 600 ppm. The waters with a concentration of chlorides less than 150 ppm are considered to be quite safe and as the concentration approaches 3000 it is found to be quite hazardous.[5]

Concentration of bicarbonates from 10 to 20 meq/l have been reported to be causing iron chlorisis in certain plants.[31]

The boron content of domestic sewage ranges from 0.04 to 1.0 ppm. Boron has been proved to be toxic to most plants at 1 to 2 mg/l.[34]

2.6.4. Efficiency of Treatment Systems:

The main object of the treatment units is to reduce the various sewage contents (solids) from the sewage and change the character of the sewage in such a way that either it can be safely utilized for irrigation or discharged into the natural water course. The degree of treatment will be decided by the extent to which the final products of treatment are to be utilized. Relative efficiencies of various types of treatment units[43] are presented in Table 2.3.

The sewage treatment plants constructed in our country vary from the simplest (the septic tanks) to the most complex (the activated sludge plants with sludge digestion). The relative costs of waste treatment plants in India for populations ranging from 5000 to 200,000 as worked out by Mohan Rao[1] are presented in Table 2.4.

Table 2.3

Relative efficiencies of sewage treatment plant units [43]

S. No.	Treatment process unit	Suspended solids	% removal of	
			5 day 20°C B.O.D.	Bacteria
1.	Fine screens	2 to 20	5 to 10	10 to 20
2.	Chlorination of settled sewage	-	15 to 30	90 to 95
3.	Plain settling tanks	40 to 70	25 to 40	25 to 75
4.	Chemical precipitation	70 to 90	50 to 85	40 to 80
5.	High rate trickling filters preceded and followed by plain sedimentation	65 to 92	65 to 95	80 to 95
6.	Low rate -do-	70 to 92	80 to 95	90 to 95
7.	High rate activated sludge treatment preceded and followed by plain sedimentation	65 to 95	65 to 95	80 to 95
8.	Conventional activated -do-	85 to 90	75 to 95	90 to 98
9.	Intermittent sand filteration	85 to 95	60 to 95	95 to 98
10.	Chlorination of biologically treated sewage	-	-	98 to 99

Table 2.4

Relative costs of waste treatment plants in India (0.15 to 6 MGD)[1]

S. No.	Process	Cost per capita for construction of plant including land cost Rs.	Capital cost + capitalised running costs per capita Rs.	Total annual expenditure Rs.
1.	Waste stabilization pond	8.80 - 15.70	10.60 - 27.20	0.93 - 2.30
2.	Aerated lagoon	12.00 - 19.00	32.20 - 55.80	2.80 - 4.86
3.	Oxidation ditch	14.00 - 21.00	43.75 - 79.60	3.80 - 6.06
4.	Conventional treatment	25.00 - 75.00	40.88 -152.00	3.55 - 13.22

The fertilizing values of an average sewage are approximately the same for primary treated sewage as for raw sewage.[52] Sewage effluent following secondary treatment had lost a substantial part of nutrients as shown in Table 2.5.

Table 2.5

Nutrient content of sewage[52]

Sewage	Total Nitrogen	Total Potash as K_2O	Total Phosphorus as P_2O_5
Raw untreated	66.2	42.1	22.6
Primary treated	73.3	43.2	23.5
Secondary treated	17.2	37.0	17.6
Drainage water from farm field	12.7	20.0	8.4

2.7. Summary:

A study of literature presented in the preceding paragraphs brings out the following few facts:

1. The use of sewage for irrigation has widely been appreciated due to its water and nutritious contents but equally condemned because of its adverse effects on public health, crops grown and soil in the long run.
2. The adverse effects of the sewage contents, however, depends on various factors, major among them being, permeability and constitution of soil, tolerance of different crops, quantity and rate of application of

sewage, concentration of these contents and various other climatic and management factors.

3. The pathogens if present in sewage will contaminate the crops which in turn may pass on the infection to the consumers. The farm workers who are in direct contact with the sewage effluent, contaminated soil or crops, are more exposed to such infections.
4. Recently the necessity of treating the sewage before its application on farms has been well recognized. This is mainly because of the realization to have a better environment and improved public health.
5. Generally the efficiency of any treatment system is viewed from its BOD and suspended solids removal capability and accordingly the treatment process is recommended irrespective of the mode of effluent disposal.
6. The conventional treatment systems are not found to be very effective in pathogen removal.

2.8. <u>Need for Present Work</u>:

Knowing the good and bad points of sewage farming and recognizing the necessity of improving the quality of sewage before its use for irrigation, an effort, therefore, is required to quantify different quality factors collectively and to propose the appropriate treatment technology for the extraction of such constituents to a level acceptable for the purpose.

Formation of an index specifically for the use of sewage for farming may serve the purpose, as it is doing in the case of water. Such an index may be defined as a rating reflecting

the composite influence on overall quality of a number of individual quality characteristics.

Indicies previously formed are mainly for quantifying the factors contributing towards drinking water quality or in the case of wastewater, for improving its quality suitable for discharging into water ways.[44-47] These may serve as the guidelines for developing a wastewater quality index for sewage farming.

3. FORMULATION OF WASTEWATER QUALITY INDEX

The work of formulation of the index has been divided into three parts:

1. Selection of wastewater parameters, affecting the public health, crops and soils adversely when used for farming.
2. Allocation of different ratings and weightages to the parameters.
3. Calculation of the index value based on data collected.

3.1. Selection of Parameters:

Selection of quality parameters on which the index is to be based,is significant because the total characteristics are too large in number that would make the index unwieldy. It appears practical to use only those parameters that are of the greater importance.

3.1.1. Parameters Affecting Health:

The different pathogens present in sewage, which have been identified to be responsible for causing various disease, are viruses, bacteria, protozoa and helminths. It is their quantification which will reflect the quality of wastewater and its effects on the health of farm workers as well as human and animal consumers of the farm product.

(a) Health of Workers: Since the farm workers are the first ones to come in contact with the sewage, immediately on its application to the fields, they are exposed to the attack of all the pathogens, viz., viruses, bacteria, protozoa and helminths, present in sewage applied.

Some previous studies[7] to assess the health conditions of farm workers, in our country, point out that the most prevailing out of all the diseases are hookworm and some skin diseases which are caused by helminths. Their general habit of moving about barefoot may be one of the causes. Amoebic dysentry is found to be next in the list. This is caused by protozoa (Entamoeba histolytica) usually present in wastewater. Their living and sanitary conditions also seem to be responsible for some bacterial infections found to be more in farm workers than the other control population. Though, not many viral infections have been recorded amongst farm workers particularly, but considering their exposure to numerous viruses present in sewage, especially under the existing protective measures, virus also has been selected to be measured though the last in the list.

(b) Health of Human Consumers: Excepting for perhaps protozoa, whose survival on crops has been reported to be about 2 days, all other pathogens have been found to have sufficient survival time on crops to be transported into markets and then to homes and subsequently infect those who handle, prepare or eat the crop. Diseases caused by virus and bacteria, through this mode, have been reported equally and frequently. This is mainly so because of their asexual multiplication. In contrast the helminths multiply bisexually and generally do not grow within human hosts.

(c) Health of Animal Consumers: Domestic wastewater, though may not contain significant amount of pathogens responsible for transmitting diseases of veternary importance, the presence

of *Taenia saginata*, *Salmonella* and tubercle bacilli, responsible to cause beef tapeworm, salmonellosis and tuberculosis respectively, has been reported.

Considering the number of these pathogens generally present in domestic sewage and the required doses reported to cause infection amongst animals, only helminth (*Taenia*) ova are selected for the purpose of this study.

The parameters, thus finally selected to be included in the formation of index are listed below in the descending order of importance, under different classes.

Workers	:	Helminth (hookworm), protozoa (*Antamoeba histolytica*), bacteria (*E. coli*) and viruses (Enteric viruses).
Human consumers	:	Enteric viruses, *E. coli*, helminth (*Ascaris*) ova.
Animal consumers	:	Helminth (*Taenia*) ova.

3.1.2. Parameters Affecting Crops:

(1) Electrical Conductivity (EC): The effect of salinity (measured as EC) on the osmotic pressure of soil solution relates to the availability of water for plant consumption. High salinity creates a physiological drought condition for the plants, even in the presence of adequate water content in the soil. Since only pure water is lost to the atmosphere during evapo-transpiration, the salt concentration of soil increases rapidly. This in turn increases the solute suction, the force with which water is withheld from plant up-take.

Plants require balanced nutrient content in the soil solution to maintain optimum growth. Depending upon its

composition and concentration, saline water may, at times, upset the balance. A very common effect of salinity is to give stunted growth to plant which may consequently wilt. The process of wilting starts at what stage, will depend upon the salt tolerance of the plant. Plants vary in their tolerance to soil salinity and accordingly divided into the categories of high salt tolerant, medium salt tolerant and low salt tolerant.

(2) Sodium: Plants irrigated with waters having high sodium content will be deficient in their calcium content. This will be so, because calcium will get desorbed when higher content of sodium is adsorbed by the soil. Under such conditions the plants with high calcium requirement will usually suffer.

Also certain sodium sensitive plants (some fruit varieties) may suffer injury as a result of an accumulation of sodium in plant tissues, even, when the concentrations are lower than those harmful to the soil.

(3) Bicarbonates: The bicarbonate ion affects the up-take and metabolism of nutrients by plants. This may result in cation accumulation of some and deficiency of others in the plant body. Bicarbonates sometimes exert specific toxic effects on some plant species resulting in serious injury even at low osmotic concentrations.

(4) Chlorides: Excessive chlorides may have a direct toxic effect on fruit crops by causing scorching of leaves and severe injury. Excepting for the sensitive fruit crops, other crops are not likely to be affected badly with moderate

concentration of chlorides in irrigation waters, since, these will generally be leached out with average rain water.

(5) Trace Elements: Trace elements like boron, iron, copper, manganese and zinc are the micro-nutrients essential for plant growth. These may prove to be poisonous to sensitive plants, if present, in excessive quantities. Recommended maximum concentrations[31] are presented in Table 3.1. Out of these boron is considered to be most essential to the normal growth of all plants, but the quantity required is very small (a few tenths mg/l). Apart from boron (in the form of detergents) the domestic sewage is not likely to contain any of the other trace elements in limits toxic to plants, unless some industrial wastewaters are discharged into it; a case not under the scope of this study. Hence this parameter has not been included in the formation of index.

Table 3.1

Recommended maximum concentrations of trace elements in irrigation waters[31]

Element	For waters used continuously on all soils mg/l
Aluminium	5.00
Arsenic	0.10
Boron	0.75
Cadmium	0.01
Chromium	0.10
Cobalt	0.05
Copper	0.20
Fluoride	1.00
Iron	5.00
Lead	5.00
Manganese	0.20
Nickel	0.20
Zinc	2.00

(6) Temperature: Very high or very low temperature of irrigation water has a direct effect on plant growth. This effect on plant growth occurs when the water is just applied and it comes in direct contact with the plant body. This factor, though important, has not been selected, as the temperature of domestic sewage in our country is not likely to achieve such high or low values to damage the plants.

3.1.3. Parameters Affecting Soils:

(1) Sodium: Sodium is considered as the most hazardous sewage content for the soil, whenever irrigation with sewage is planned. This is so, because the effect of other constituents reduces considerably if the permeability of soil is good; whereas, sodium's main attack is on the permeability itself.

Calcium and magnesium are the principal cations found in normal productive soils and have a favourable effect upon the physical condition of any soil. If soils come in contact with high sodium irrigation water, sodium is adsorbed by the soil exchange complex and when it adsorbs sodium it has to deprive itself of certain cations of calcium and magnesium. In view of these facts, sodium is a very important factor in evaluating the quality of wastewater for irrigation.

(2) Electrical Conductivity (EC): The salt concentration of soil solution gets disturbed when irrigated with saline water and during this the translocation of salts is brought about. If drainage is poor the salts may either accumulate in root zones affecting the crops or appear on soil surface

creating salt efforescence. However, if the accumulation is uniform throughout no serious detrimental effects arise. Considering these facts the values of EC must be brought within harmless limits before the use of sewage for irrigation.

(3) pH: pH of the soil solution influences many physical and chemical properties of soil that govern the growth of plants and the activities of micro-organisms in the soil. A pH range from 6.5 to 7.5 approximately, has been found to be conducive for the availability of most plant nutrients.[31] This also is the most suitable range for biological environment. Although the soil is a buffered system (except, for sandy soils) and the pH of the soil may not be altered very easily, the pH values below 4.8 and above 8.3 will adversely affect the exchangeability of calcium and magnesium.[31]

(4) Suspended Solids: The suspended solids, if applied in excess, may form a crust on most of the soil surfaces reducing the permeability and aeration of soil; both being very important for the success of the sewage irrigation system. Though the principal agricultural operations like ploughing and weeding etc., may help to some extent in maintaining the crumb structure, the reduction of suspended solids for the better functioning of the system is still required.

(5) BOD: When sewage with high strength BOD is applied to the soil, the oxygen in the soil pores is rapidly used up for the satisfaction of BOD. This results in oxygen depletion of the soil, more so, if the soil is not well structured and poor drainage exists. Lack of soil oxygen will affect the

root respiration and many other biological processes in the soil.

Though, restoration of soil oxygen levels in the soil pores can be achieved to some extent by providing rest periods between irrigations and lowering the application rates the effect of high BOD waters on soil cannot be completely ignored.

3.2. Allocation of Rating Scales:

Scales have been chosen so that each characteristic can be assigned a value from 0 to 10 with an increment of 2 i.e. 0, 2, 4, 6, 8 and 10, depending upon its concentration. The process of earmarking different ratings to different ranges of parameters, has been further divided to represent the degree of their effect on various aspects of sewage farming separately and is described below.

3.2.1. Health:

Factors affecting health, as discussed earlier, have been grouped in three separate groups, viz., health of workers, health of human consumers and health of animal consumers.

In the first case, i.e., health of workers, irrespective of the type of crops grown and type of soil, the workers will be equally exposed to the infections caused by pathogens present in sewage. Same will be applicable in the case of animals who consume sewage grown fodder. In the case of human consumers, however, the actual pathogens finally reaching the human population, will vary with the type of crops grown,

i.e., vegetables and field crops. The effect of different pathogens, therefore, has been considered to be different in both these categories, which are allotted different ratings. No differentiation, however, has been made amongst the vegetables to be eaten raw and those to be cooked because for those who handle and cook these vegetables, the degree of risk is same in both cases.

Based on the above facts different ratings allotted to health of human consumers, health of animals and health of workers are presented in Tables 3.2, 3.3 and 3.4 respectively.

3.2.2. Crops:

The effect of various chemical constituents of sewage on the crops, grown on any sewage farm, will be different on different varieties of crops depending upon their tolerance to such constituents. Though, it is not necessary that a particular type of crop which is tolerant to say sodium, must also have the same degree of tolerance to chlorides, but generally, considering the accumulative effect of different constituents, it can safely be concluded that fruit and vegetable crops are the most sensitive and fodder crops the most tolerant (Table 3.5).

Accordingly the crops have been grouped into three categories as:

Fodder and grass	-	Tolerant
Field crops	-	Moderately tolerant
Fruits and vegetables	-	Sensitive

Different rating scales have, therefore, been allotted to

Table 3.2

Wastewater parameters affecting health of human consumers and respective rating scales

S. No.	Parameters and their ranges	Ratings with respect to	
		Fruit and vegetable crops	Field crops
1.	Enteric viruses (No./l)		
	$\leqslant 100$	8	10
	>100 and $\leqslant 1000$	6	8
	>1000 and $\leqslant 5000$	4	6
	>5000	2	4
2.	<u>E. coli</u> (No./l)		
	$\leqslant 1000$	8	10
	>1000 and $\leqslant 5000$	6	8
	>5000 and $\leqslant 10{,}000$	4	6
	$>10{,}000$	2	4
3.	<u>Ascaris</u> ova (No./l)		
	$\leqslant 50$	8	10
	>50 and $\leqslant 100$	6	8
	>100 and $\leqslant 500$	4	6
	>500	2	4

Table 3.3

Wastewater parameters affecting health of animals and respective rating scales

S. No.	Parameters and their ranges	Ratings
1	<u>Taenia</u> ova (No./l)	
	$\leqslant 5$	10
	>5 and $\leqslant 10$	8
	>10 and $\leqslant 50$	6
	>50	4

Table 3.4

Wastewater parameters affecting health of farm workers and respective rating scales

S. No.	Parameters and their ranges	Ratings
1.	Enteric viruses (No./l)	
	≤ 100	10
	>100 and ≤ 1000	8
	>1000 and ≤ 5000	6
	>5000	4
2.	E. coli (No./l)	
	≤ 1000	10
	> 1000 and ≤ 5000	8
	> 5000 and ≤ 10,000	6
	>10,000	4
3.	Entamoeba histolytica cysts (No./l)	
	≤ 100	10
	>100 and ≤ 500	8
	>500 and ≤ 1000	6
	>1000	4
4.	Hookworm ova (No. l)	
	≤ 50	10
	> 50 and ≤ 100	8
	>100 and ≤ 500	6
	>500	4

Table 3.5

Relative tolerance of crop plants to salt[36]

High salt tolerance	Medium salt tolerance	Low salt tolerance
FRUIT CROPS		
Date palm	Pomegranate	Pear
	Fig	Apple
	Olive	Orange
	Grape	Grapefruit
	Cantaloupe	Prune
		Plum
		Almond
		Apricot
		Peach
		Strawberry
		Lemon
		Avocado
VEGETABLE CROPS		
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 4$
Garden beats	Tomato	Radish
Kale	Broccoli	Celery
Asparagus	Cabbage	Green beans
Spinach	Bell pepper	
	Cauliflower	
	Lettuce	
	Sweet corn	
$EC_e \times 10^3 = 10$	Potatoes (white rose)	$EC_e \times 10^3 = 3$
	Carrot	
	Onion	
	Peas	
	Swuash	
	Cucumber	
	$EC_e \times 10^3 = 4$	
FORAGE CROPS		
$EC_e \times 10^3 = 18$	$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$
Alkali sacaton	White sweetclover	White Dutch clover
Saltgrass	Yellow sweetclover	Meadow foxtail
Nuttall Alkaligrass	Perennial ryegrass	Alsike clover
Bermuda grass	Mountain brome	Red clover
Rhodes grass	Strawberry clover	Ladino clover
Rescue grass	Dallis grass	Burnet
Canada wildrye	Sudan grass	
Western wheatgrass	Hebam clover	

Continued...

Table 3.5 (Contd.)

High salt tolerance	Medium salt tolerance	Low salt tolerance
Barley (hay) Bridsfoot trefoil	Alfalfa (California common) Tall fescue Rye (hay) Wheat (hay) Oats (hay) Orchard grass Blue grama Meadow fescue Reed canary Big trefoil Smooth brome Tall meadow oatgrass Cicer milkvetch Sourclover Sickle milkvetch	
$EC_e \times 10^3 = 12$	$EC_e \times 10^3 = 4$	$EC_e \times 10^3 = 2$
FIELD CROPS		
$EC_e \times 10^3 = 16$ Barley (grain) Sugarbeet Rape Cotton	$EC_e \times 10^3 = 10$ Rye (grain) Wheat (grain) Oats (grain) Rice Sorghum (grain) Corn (Field) Flax Sunflower Castor beans	$EC_e \times 10^3 = 4$ Field beans
$EC_e \times 10^3 = 10$	$EC_e \times 10^3 = 6$	

Note: The numbers following $EC_e \times 10^3$ are the electrical conductivity values of the saturation extract in mmho/cm at 25°C and associated with 50% decrease in yield. EC_e values refer to the electrical conductivity values of the saturation extract of soil and that these figures may be 2 to 10 times that of the conductivities of irrigation water.

Within each group, the crops are listed in the order of decreasing salt tolerance.

these three classes, the most stringent being for the fruit and vegetable crops (Table 3.6).

For the purpose of this study, any crop grown for the exclusive consumption of animals has been grouped into fodder crops. All those crops, like cereals and industrial crops which are to be used by human consumers only after processing, have been combined under field crops and all types of fruits and vegetables whether eaten raw or cooked, are grouped as fruit and vegetable crops.

3.2.3. Soils:

Different types of soils will behave differently, when irrigated with sewage, because of their varying permeability rates, chemical constituents, particle concentration and various other characteristics. In the present study the above facts have been regarded by allocating different rating scales to different types of soils grouped in four categories, viz., sandy soil, sandy-loam, clayey-loam and clayey soil in their descending order of tolerance to all the parameters (except pH). In the case of pH the order is reverse since sandy soil has been reported to be completely unbuffered.[31] Accordingly different rating scales are allotted to each group of soil (Table 3.7).

In general, depending on the grain size analysis, the soils are grouped under various categories as shown in Figure 3.1.[50] To restrict the scope of this study, the soils are re-grouped as follows:

Table 3.6

Wastewater parameters affecting crops and respective rating scales

S. No.	Parameters and their ranges	Ratings		
		Fruits and vegetable crops	Field crops	Fodder crops
1.	SAR			
	$\leqslant 4$	6	8	10
	> 4 and $\leqslant 6$	4	6	8
	> 6 and $\leqslant 10$	2	4	6
	> 10	0	2	4
2.	EC (micromhos/cm)			
	$\leqslant 250$	6	8	10
	> 250 and $\leqslant 750$	4	6	8
	> 750 and $\leqslant 2250$	2	4	6
	> 2250	0	2	4
3.	Chlorides (mg/l)			
	$\leqslant 150$	8	10	10
	> 150 and $\leqslant 200$	6	8	8
	> 200 and $\leqslant 300$	4	6	6
	> 300	2	4	4
4.	Bicarbonates (mg/l)			
	$\leqslant 90$	6	8	10
	> 90 and $\leqslant 300$	4	6	8
	> 300 and $\leqslant 520$	2	4	6
	> 520	0	2	4

Table 3.7

Wastewater parameters affecting soils and respective rating scales

S. No.	Parameters and their ranges	Ratings			
		Sandy	Sandy loam	Clayey loam	Clayey
1.	SAR				
	≤ 4	10	10	8	6
	> 4 and ≤ 10	8	8	6	4
	> 10 and ≤ 18	6	6	4	2
	> 18	4	4	2	0
2.	EC (micromhos/cm)				
	≤ 250	10	10	8	6
	> 250 and ≤ 750	8	8	6	4
	> 750 and ≤ 2250	6	6	4	2
	> 2250	4	4	2	0
3.	pH				
	≥ 6.5 and ≤ 7.5	6	8	10	10
	> 6 and < 6.5 or > 7.5 and ≤ 8	4	6	8	8
	> 5 and ≤ 6 or > 8 and ≤ 9	2	4	6	6
	< 5 or > 9	0	2	4	4
4.	Suspended solids (mg/l)				
	≤ 70	10	8	8	6
	> 70 and ≤ 150	8	6	6	4
	> 150 and ≤ 200	6	4	4	2
	> 200	4	2	2	0
5.	BOD (mg/l)				
	≤ 100	10	8	8	6
	> 100 and ≤ 200	8	6	6	4
	> 200 and ≤ 300	6	4	4	2
	> 300	4	2	2	0

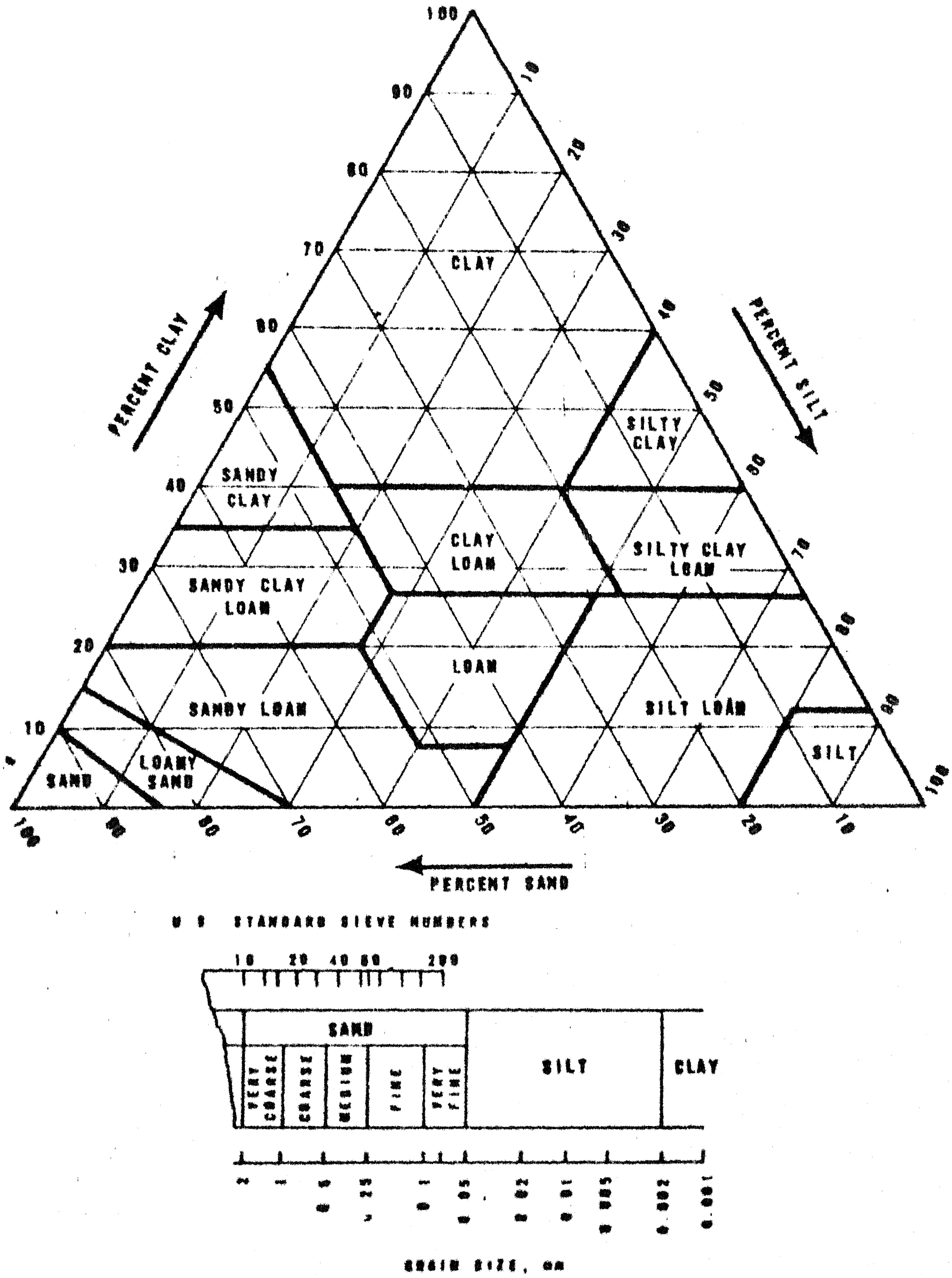

Figure 3.1. Proportions of sand, silt, and clay in the basic soil - textural classes.(50)

1. Sandy soil to include - Sand and loamy sand
2. Sandy-loam to include - Sandy loam, loam and silt loam
3. Clayey loam to include - Clay loam, sandy clay loam, silty clay loam and silt
4. Clayey soil to include - Clay, silty clay and sandy clay.

Values suggested in four different ranges for each parameter have been chosen to be the safest ones out of those reviewed in the literature. These suggestions, however, have been based on either one or both of the following factors:

(i) Experience of past workers quoted in the literature review

(ii) The practicability of achieving these figures through available and economical treatment technology.

Inspite of these considerations, it should be pointed out that all of these ranting values are subjective and may have some difference of opinion.

3.3. <u>Weighting of Parameters</u>:

The next step in development of the index is to give weightage to different parameters to show their relative importance in their respective classes, viz., health, crops and soils. The weight allotted to each parameter is a number between 0 and 1 such that

$$\sum_{i=1}^{n_i} w_i = 1$$

Based on the discussion held earlier (Sections 2.6 and 3.1) different weights allotted to different parameters, in all the three classes are listed in Table 3.8.

Table 3.8

Weighting of Parameters

Parameters	Weight	Parameters	Weight
<u>Health of Workers</u>		<u>Crops</u>	
1. Helminth (Hookworm) ova	0.35	1. EC	0.50
2. Protozoa (<u>Entamoeba hystolytica</u>) cysts	0.30	2. SAR	0.20
3. Bacteria (<u>E. coli</u>)	0.20	3. Bicarbonates	0.20
4. Viruses (Enteric viruses)	0.15	4. Chlorides	0.10
<u>Health of Human Consumers</u>		<u>Soils</u>	
1. Viruses (Enteric viruses)	0.40	1. SAR	0.35
2. Bacteria (<u>E. coli</u>)	0.40	2. EC	0.30
3. Helminth (<u>Ascaris</u>) ova	0.20	3. pH	0.20
<u>Health of Animal Consumers</u>		4. Suspended solids	0.10
1. Helminth (<u>Taenia</u>) ova	1.00	5. BOD	0.05

3.4. <u>Calculation of Index Value</u>:

(a) <u>Based on Weighted Mean</u>: For developing a weighted mean index, after selection of parameters, development of rating scales and assignment of relative weights, all that remains to be done is to combine the various elements into a single index number. This is done with the help of a simple cumulative formula as given below:

$$WMI = \sum_{i=1}^{n} w_i \, r_i$$

where WMI = weighted mean index, a number between 0 and 10

r_i = rating of ith parameter, a number between 0 and 10

w_i = the unit weight of the ith parameter, a number between 0 and 1, such that

$$\sum_{i=1}^{n} w_i = 1$$

where n = number of parameters.

On the basis of above formula, an optimum index, $WMI_{(O)}$, is calculated by substituting the values of r_i by the highest rating allotted to each parameter, for each sub-case under different categories of health, crops and soils. Such optimum indices are calculated and presented in Tables 3.9, 3.10 and 3.11 respectively. Similarly, based on the data collected, a separate index for each city under consideration is calculated for all the sub-cases, compared with its respective $WMI_{(O)}$ and classified into either suitable or unsuitable group.

The classification so carried out since is based on individual subjective ratings, may not always be correct. Especially, when two wastewaters are fairly similar with respect to the values of their parameters, it may not be possible to classify those satisfactorily because of the large amount of overlap between the two groups. Technique of discriminant analysis is, therefore, applied to differentiate between various wastewaters and classify them as suitable or unsuitable, with a higher degree of confidence. The procedure under this analysis consists of finding a linear combination of the parameters such that the distributions for the two groups will possess "little" overlap.[51]

Table 3.9

Values of optimum weighted mean indices ($WMI_{(O)}$) for health of human consumers, animals and farm workers

Parameters	Weight[a]	Maximum rating scale[b]	Maximum value of WMI ($WMI_{(M)}$) ($\sum_{i=1}^{n} w_i r_i$)	Optimum value of WMI ($WMI_{(O)}$) (($WMI_{(O)}$) = (0.8 x $WMI_{(M)}$)
HEALTH (HUMAN CONSUMERS)				
(a) w.r.t. Vegetable crops				
Enteric viruses	0.4	8	(8x.4)+(8x.4)+(8x.2) = 3.2 + 3.2 + 1.6 = 8.0	8 x .8 = 6.4
E. coli	0.4	8		
Ascaris ova	0.2	8		
(b) w.r.t. Field crops				
Enteric viruses	0.4	10	(10x.4)+(10x.4)+(10x.2) = 4 + 4 + 2 = 10.0	10 x .8 = 8.0
E. coli	0.4	10		
Ascaris ova	0.2	10		
HEALTH (ANIMALS)				
Taenia ova	1.0	10	10 x 1.0 = 10.0	10 x .8 = 8
HEALTH (WORKERS)				
Hookworm ova	0.35	10	(10x.35)+(10x.30)+(10x.20) +(10x.15) = 3.5 + 3.0 + 2.0 + 1.5 = 10.0	10 x .8 = 8.0
Amoeba cysts	0.30	10		
E. coli	0.20	10		
Enteric viruses	0.15	10		

Note: (a) Weights are taken from Table 3.7.
(b) Maximum rating scale is taken from Tables 3.1, 3.2 and 3.3.

Table 3.10

Values of optimum weighted mean indices ($WMI_{(O)}$) for crops

Parameters	Weight[a]	Maximum[b] rating scale	Maximum value of WMI ($WMI_{(M)}$) $(\sum_{i=1}^{n} w_i r_i)$	Optimum value WMI (WMI(O)) (($WMI_{(O)}$) = (0.7 x $WMI_{(M}$
Fruit & Vegetable Crops				
SAR	0.2	6	(6x.2)+(6x.5)+(6x.1)+(6x.2)	6.2 x .7
EC	0.5	6	= 1.2 + 3.0 + 0.8 + 1.2	
Chlorides	0.1	8	= 6.2	= 4.3
Bicarbonates	0.2	6		
Field crops				
SAR	0.2	8	(8x.2)+(8x.5)+(10x.1)+(8x.2)	8.2 x .7
EC	0.5	8	= 1.6 + 4.0 + 1.0 + 1.6	
Chlorides	0.1	10	= 8.2	= 5.7
Bicarbonates	0.2	8		
Fodder crops				
SAR	0.2	10	(10x.2)+(10x.5)+(10x.1)+(10x.2)	10 x .7
EC	0.5	10	= 2.0 + 5.0 + 1.0 + 2.0	= 7.0
Chlorides	0.1	10	= 10.0	
Bicarbonates	0.2	10		

Note: (a) Weights are taken from Table 3.7.
(b) Maximum rating scale is taken from Table 3.5.

Table 3.11

Values of optimum weighted mean indices ($WMI_{(O)}$) for soils

Parameters	Weight[a]	Maximum[b] rating scale	Maximum value of WMI ($WMI_{(O)}$) $(\sum_{i=1}^{n} w_i \ r_i)$	Optimum value of WMI ($WMI_{(O)}$) (($WMI_{(O)}$) = (0.7 x $WMI_{(M)}$)
Sandy soil				
SAR	0.35	10		
EC	0.30	10	(10x.35)+(10x.30)+(6x.2)+(10x.1)	
pH	0.20	6	+(10x.05)	
Suspended solids	0.10	10	= 3.5 + 3.0 + 1.2 + 1.0 + 0.5	9.2 x .8
BOD	0.05	10	= 9,2	7.3
Sandy loam soil				
SAR	0.35	10		
EC	0.30	10	(10x.35)+(10x.3)+(8x.2)+(8x.1)	
pH	0.20	8	+(8x.05)	
Suspended solids	0,10	8	= 3.5 + 3.0 + 1.6 + 0.8 + 0.4	9.3 x .8
BOD	0.05	8	= 9.3	7.5
Clayey loam soil				
SAR	0.35	8		
EC	0.30	8	(8x.35)+(8x.3)+(10x.2)+(8x.1)	
pH	0.20	10	+(8x.05)	
Suspended solids	0.10	8	= 2.8 + 2.4 + 2.0 + 0.8 + 0.4	8.4 x .8
BOD	0.05	8	= 8.4	6.7
Clayey soil				
SAR	0.35	6		
EC	0.30	6	(6x.35)+(6x.3)+(10x.2)+(6x.10)	
pH	0.20	10	+(6x.05)	6.8 x .8
Suspended solids	0.10	6	= 2.1 + 1.8 + 2.0 + 0.6 + 0.3	
BOD	0.05	6	= 6.8	5.4

Note: (a) Weights are taken from Table 3.7.
(b) Maximum rating scale is taken from Table 3.6.

(b) Based on Discriminant Analysis: Discriminant analysis treats the problem of attempting to differentiate between two or more classes of objects. To that purpose we set up an index which classifies an object belonging to one group or the other. This index is a linear combination of the measurements taken on a subject. In addition a certain critical value, Y*, for the index is established such that if the index value for a given object falls below the critical value the object will be classified in one group; if the object's index value falls above the critical value this will be classified in the other group. The procedure of finding a linear combination of the measures and calculating the critical value, Y*, is described in Appendix A.

3.4.1. Collection of Data:

The data required to establish the critical value, Y*, were collected from a few representative cities of the country where sewage is used for farming in an organised manner with or without any treatment. The data on physico-chemical characteristics of wastewater, selected to be included in the formation of the index for each sub-case, are listed city-wise in Table 3.12. Certain values of the physico-chemical parameters on which information could not be obtained from a few cities, have been proratedly assumed on the basis of concentration of other constituents of that wastewater.

No information, however, was available, at any of the places visited, on the biological characteristics of the wastewater. Hence for the purpose of this study the selected

Table 3.12

Data on physico-chemical characteristics of wastewaters selected to be included in the formation of index

S. No.	Name of city	Type of effluent	Parameters and their characteristics						
			SAR	EC (micro-mhos/cm)	pH	Suspended solids (mg/l)	BOD (mg/l)	Chlorides (mg/l)	Bicarbonates (mg/l)
1	2	3	4	5	6	7	8	9	10
1.	Madurai	Raw sewage	(3.1)	1200	7.1	380	200	220	(245)
2.	Madras (Nessapakkam)	Activated sludge	4.3	2260	7.3	110	105	343	283
3.	Hyderabad	Septic tank (diluted)	(3.0)	958	7.5	210	100	82	280
4.	Pune	Settled and diluted sewage	(2.8)	520	7.3	190	100	52	162
5.	Bombay (Dadar)	Activated sludge	3.31	1250	7.2	120	110	268	341
6.	Bombay (Khar)	Settled sewage	5.77	3687	6.9	152	251	900	264

Contd...

Table 3.12 (Continued)

1	2	3	4	5	6	7	8	9	10
7.	Bombay (Worli)	Settled sewage	7.23	2800	6.9	124	92	856	321
8.	Bombay (Versova)	Settled sewage	16.22	7047	7.6	240	150	1750	257
9.	Delhi (Okhla)	Activated sludge	(3.22)	1060	7.5	21	15	155	350
10.	Jamshedpur	Activated sludge	2.80	500	7.3	10	12	34	172

Note: Values in parenthesis are proratedly assumed.

biological characteristics of the effluent from different treatment systems are taken from literature as cited in Table 3.13.

Table 3.13

Pathogen removal efficiencies of various treatment processes[20]

Treatment process	Parameters	Organisms					
		Enteric viruses	*E. coli*	Amoeba cysts	*Ascaris* ova	Hook-worm ova	*Taenia* ova
1	2	3	4	5	6	7	8
Primary sedimentation	(a)	10^3-10^5	10^6-10^8	10-10^4	10-10^3	10-10^3	1-100
	(b)	10^3-10^5	10^5-10^7	5-10^4	1-10	10-10^2	0.1-50
	(c)	0-30%	50-90%	10-50%	30-80%	50%	50-90%
Trickling filter	(a)	10^3-10^5	10^6-10^8	10-10^4	10-10^3	10-10^3	1-100
	(b)	10^2-10^4	10^5-10^7	5-10^3	0-10^2	10-10^2	0.1-50
	(c)	90-95%	90-95%	50% ?	70-100%	50-90%	50-95%
Activated sludge	(a)	10^3-10^5	10^6-10^8	10-10^4	10-10^3	10-10^3	1-100
	(b)	10-10^4	10^4-10^7	5-10^3	0-10^2	10-10^2	0.1-50
	(c)	90-99%	90-99%	50% ?	70-100%	50-90%	50-95%
Oxidation ditch	(a)	10^3-10^5	10^6-10^8	10-10^4	10-10^3	10-10^3	1-100
	(b)	10-10^4	10^4-10^7	5-10^3	0-10^2	10-10^2	0.5-50
	(c)	90-99%	90-99%	50% ?	70-100%	50-90%	50% ?

Contd...

Table 3.13 (Continued)

1	2	3	4	5	6	7	8
Waste stabilization ponds (3 cells)	(a)	10^3-10^5	10^6-10^8	$10-10^4$	$10-10^3$	$10-10^3$	1-100
	(b)	0-10	$10-10^4$	0	0	0	0
	(c)	99.99-100%	99.99-99.9999%	100%	100%	100%	100%
Septic tanks	(a)	$0-10^9$	10^7-10^9	$0-10^5$	$0-10^4$	$0-10^4$	$0-10^3$
	(b)	$0-10^8$	10^6-10^8	$0-10^5$	$0-10^3$	$0-10^3$	0-500
	(c)	50%	50-90%	0% ?	50-90%	50-90%	50-90%
Lagoons as tertiary treatment	(a)	$10-10^4$	10^4-10^7	$10-10^3$	$10-10^2$	$10-10^2$	0.1-50
	(b)	$0-10^2$	$10-10^5$	0	0	0	0
	(c)	99-100%	99-99.999%	100%	100%	100%	100%
Land application	(a)	$10-10^4$	10^4-10^7	$10-10^3$	$0-10^2$	$10-10^2$	0.1-50
	(b)	$0-10^2$	$0-10^3$	0	0	0	0
	(c)	99-100%	99.99-100%	100%	100%	100%	100%
Chlorination		May survive	A few may survive (Regrowth likely)	Probably eliminated	Will survive	Will survive	Will survive

Legend: (a) - Typical inflow

(b) - Typical outflow

(c) - Percent removal.

4. RESULTS AND DISCUSSION

Using the values of optimum weighted mean indices ($WMI_{(O)}$), the data on the quality of wastewater from different cities are evaluated and classified into two groups, i.e., suitable and unsuitable. The results of this classification are further subjected to a more rigorous technique of classification, i.e., discriminant analysis, which after correcting the errors of the previous classification, if any, reclassifies the wastewaters into their specific groups. The results of evaluation of 10 different wastewaters pertaining to seven cities are presented in Tables 4.1 to 4.11.

Each such table deals with either an aspect of health or a type of crop or the kind of soil and presents the results in the following sequence.

Firstly, the results of classification of all the wastewaters are listed on the basis of weighted mean index (WMI) and then on the basis of discriminant function. The number of samples misclassified in any of the groups, that is, suitable of unsuitable, during the classification based on WMI, are indicated under a heading "summary of errors".

For calculating the index value for any given sample in future, a set of co-efficients, (the number being same as that of variables/parameters) under the heading "co-efficient variable slope", and a critical value of such an index referred to as Y* are also presented at the end of each table.

Table 4.1

****

HUMAN HEALTH(VEGETABLE CROPS)

****

IFICAITON BASED ON WEIGHTED MEAN INDEX

...ment ...ss	Enteric Virus (No./l)	E.Coli (No./l)	Ascaris ova (No./l)	Group
...ry sedimentation	10000.00	1000000.00	250.00	1
...ling filter	1000.00	1000000.00	75.00	1
...ated sludge	1000.00	100000.00	75.00	1
...tion ditch	1000.00	100000.00	75.00	1
...c tank	50000.00	10000000.00	500.00	1
...ination	1000.00	1000.00	1000.00	1
...lisation pond	10.00	5000.00	0.00	2
...ed lagoons	100.00	5000.00	0.00	2
Filtration	100.00	500.00	0.00	2

IFICAITON BASED ON DISCRIMINANT FUNCTION

1

...

...MENT ...SS	VALUE OF Y	CLASSIFICATION
...ry sedimentation	0.9786639E+00	1
...ling filter	0.3103151E+00	2
...ated sludge	0.2536077E+00	2
...tion ditch	0.2536077E+00	2
...c tank	0.2872241E+01	1
...ination	0.3128584E+01	1

2

...

...MENT ...SS	VALUE OF Y	CLASSIFICATION
...lisation pond	0.4519900E-03	2
...ed lagoons	0.1684532E-02	2
Filtration	0.1400996E-02	2

...ARRY OF ERRORS

	CORRECT	INCORRECT
...P 1	3.	3.
...P 2	3.	0.

(Contd.)

Table 4.2

****

HUMAN HEALTH(FIELD CROPS)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

Treatment Process	Enteric virus (No./l)	E.Coli (No./l)	Ascaris ova (No./l)	Gro
Primary sedimentation	10000.00	1000000.00	250.00	1
Trickling filter	1000.00	1000000.00	75.00	1
Activated sludge	1000.00	100000.00	75.00	1
Oxidation ditch	1000.00	100000.00	75.00	1
Septic tank	50000.00	10000000.00	500.00	1
Stabilisation pond	10.00	5000.00	0.00	2
Aerated lagoons	100.00	5000.00	0.00	2
Land Filtration	100.00	500.00	0.00	2
Chlorination	1000.00	1000.00	1000.00	2

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1
....

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Primary sedimentation	0.4010630E+00	1
Trickling filter	-0.2093468E+00	2
Activated sludge	-0.4008909E-01	2
Oxidation Ditch	-0.4008909E-01	2
Septic tank	0.2267926E+01	1

GROUP 2
....

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Stabilisation pond	0.4978372E-04	2
Aerated lagoons	0.8960720E-02	2
Land Filtration	0.9807009E-02	2
Chlorination	-0.1505086E+01	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	2.	3.
GROUP 2	4.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	0.9901041E-04
2	-0.1886641E-06
3	-0.1603906E-02

VALUE OF Y-STAR = 0.5216287E-01

* * * * * * * *

Table 4.3

****

HEALTH(ANIMALS)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

Treatment Process	Taenia ova (No./l)	Group
Primary sedimentation	20.00	1
Trickling filter	15.00	1
Activated sludge	15.00	1
Oxidation ditch	25.00	1
Septic tank	250.00	1
Chlorination	250.00	1
Stabilisation pond	0.00	2
Aerated lagoons	0.00	2
Land Filtration	0.00	2

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Primary sedimentation	0.1879853E+00	2
Trickling filter	0.1409890E+00	2
Activated sludge	0.1409890E+00	2
Oxidation Ditch	0.2349816E+00	2
Septic tank	0.2349816E+01	1
Chlorination	0.2349816E+01	1

GROUP 2

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Stabilisation pond	0.0000000E+00	2
Aerated lagoons	0.0000000E+00	2
Land Filtration	0.0000000E+00	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	2.	4.
GROUP 2	3.	0.

(Contd.)

```
COEFFICIENT
VARIABLE
  SLOPE

   1        0.9399264E-02

VALUE OF Y-STAR              =        0.4503814E+00
---------------

                    * * * * * * * *
```

Table 4.4

****

HEALTH(WORKERS)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

Treatment Process	Enteric Virus (No./l)	E.Coli (No./l)	Amoeba cysts (No./l)	Hookwo ova (No./l)
Primary sedimentation	10000.00	1000000.00	3000.00	50.00
Trickling filter	1000.00	1000000.00	500.00	50.00
Activated sludge	1000.00	100000.00	500.00	50.00
Oxidation ditch	1000.00	100000.00	500.00	50.00
Septic tank	50000.00	10000000.00	50000.00	500.00
Chlorination	1000.00	1000.00	100.00	2000.00
Stabilisation pond	10.00	5000.00	0.00	0.00
Aerated lagoons	100.00	5000.00	0.00	0.00
Land Filtration	100.00	500.00	0.00	0.00

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Primary sedimentation	0.4499268E+01	1
Trickling filter	0.3816548E+01	1
Activated sludge	0.3195076E+00	2
Oxidation ditch	0.3195076E+00	2
Septic tank	0.4092031E+01	1
Chlorination	0.4211181E+01	1

GROUP 2

TREATMENT PROCESS	VALUE OF Y	CLASSIFICATION
Stabilisation pond	0.2322820E-01	2
Aerated lagoons	0.5742998E-01	2
Land Filtration	0.3994478E-01	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	4.	2.
GROUP 2	3.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	0.3800198E-03
2	0.3885600E-05
3	-0.1094983E-02
4	0.1968387E-02

VALUE OF Y-STAR = 0.1458271E+01

* * * * * * * *

Table 4.5

****

CROPS(FRUIT & VEGETABLE)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	Chlorides (mg/l)	Bicarbonat (mg/l)
DELHI(Okhla)	3.22	1060.00	155.00	350.00
BOMBAY(Dadar)	3.31	1250.00	268.00	341.00
BOMBAY(Khar)	5.77	3587.00	900.00	264.00
BOMBAY(Worli)	7.23	2800.00	856.00	321.00
BOMBAY(Versova)	16.22	7047.00	1750.00	257.00
HYDERABAD	3.00	958.00	82.00	280.00
MADRAS(Nessapakkam)	4.30	2250.00	343.00	283.00
MADURAI	3.10	1200.00	220.00	245.00
JAMSHEDPUR	2.80	500.00	34.00	172.00
PUNE	2.80	520.00	52.00	162.00

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	0.6163181E+02	1
BOMBAY(Dadar)	0.6025589E+02	1
BOMBAY(Khar)	0.5911956E+02	1
BOMBAY(Worli)	0.5536799E+02	1
BOMBAY(Versova)	0.5660896E+02	1
HYDERABAD	0.5018701E+02	1
MADRAS(Nessapakkam)	0.5843189E+02	1
MADURAI	0.4453374E+02	1

GROUP 2

CITIES	VALUE OF Y	CLASSIFICATION
JAMSHEDPUR	0.2757203E+02	2
PUNE	0.2580037E+02	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	8.	0.
GROUP 2	2.	0.

(Contd.)

COEFFICIENT VARIABLE	SLOPE
1	-0.2591616E+01
2	0.1178829E-01
3	-0.1627856E-01
4	0.1714411E+00

VALUE OF Y-STAR = 0.4122565E+02

* * * * * * * *

Table 4.6

****

CROPS(FIELD)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	Chlorides (mg/l)	Bicarbonat (mg/l)
DELHI(Okhla)	3.22	1060.00	155.00	350.00
BOMBAY(Dadar)	3.31	1250.00	268.00	341.00
BOMBAY(Khar)	5.77	3687.00	900.00	264.00
BOMBAY(Worli)	7.23	2800.00	856.00	321.00
BOMBAY(Versova)	16.22	7047.00	1750.00	257.00
MADRAS(Nessapakkam)	4.30	2260.00	343.00	283.00
MADURAI	3.10	1200.00	220.00	245.00
JAMSHEDPUR	2.80	500.00	34.00	172.00
PUNE	2.80	520.00	52.00	162.00
HYDERABAD	3.00	958.00	82.00	280.00

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	0.1750188E+02	1
BOMBAY(Dadar)	0.1826904E+02	1
BOMBAY(Khar)	0.2108667E+02	1
BOMBAY(Worli)	0.1935508E+02	1
BOMBAY(Versova)	0.1859181E+02	1
MADRAS(Nessapakkam)	0.1647517E+02	1
MADURAI	0.1287510E+02	2

GROUP 2

CITIES	VALUE OF Y	CLASSIFICATION
JAMSHEDPUR	0.6194871E+01	2
PUNE	0.5851585E+01	2
HYDERABAD	0.1320271E+02	1

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	6.	1.
GROUP 2	2.	1.

(Contd.)

```
COEFFICIENT
VARIABLE
  SLOPE

   1       -0.1641028E+01

   2        0.2318120E-02

   3        0.8523698E-02

   4        0.5430746E-01

VALUE OF Y-STAR              =        0.1307639E+02
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                     * * * * * * * *
```

Table 4.7

****

CROPS(FODDER)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	Chlorides (mg/l)	Bicarbonat (mg/l)
BOMBAY(Dadar)	3.31	1250.00	268.00	341.00
BOMBAY(Khar)	5.77	3687.00	900.00	264.00
BOMBAY(Worli)	7.23	2800.00	856.00	321.00
BOMBAY(Versova)	16.22	7047.00	1750.00	257.00
MADRAS(Nessapakkam)	4.30	2260.00	343.00	283.00
DELHI(Okhla)	3.22	1060.00	155.00	350.00
JAMSHEDPUR	2.80	500.00	34.00	172.00
PUNE	2.80	520.00	52.00	162.00
HYDERABAD	3.00	958.00	82.00	280.00
MADURAI	3.10	1200.00	220.00	245.00

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

CITIES	VALUE OF Y	CLASSIFICATION
BOMBAY(Dadar)	0.6551989E+01	1
BOMBAY(Khar)	0.1246223E+02	1
BOMBAY(Worli)	0.9422200E+01	1
BOMBAY(Versova)	0.1135077E+02	1
MADRAS(Nessapakkam)	0.6335702E+01	1

GROUP 2

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	0.5239084E+01	2
JAMSHEDPUR	0.1600218E+00	2
PUNE	0.2100167E+00	2
HYDERABAD	0.3208045E+01	2
MADURAI	0.4378044E+01	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	5.	0.
GROUP 2	5.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	-0.1547740E+01
2	0.1535975E-02
3	0.1180804E-01
4	0.1932693E-01

VALUE OF Y-STAR = 0.5931810E+01
----

* * * * * * * *

4.1. Method of Evaluation of Any Wastewater:

The method of using these results in future for any wastewater is briefly discussed below.

For classifying any wastewater as suitable or otherwis the following data are required:

(i) Physico-chemical and biological characteristics of wastewater comprising of the parameters taken into account for the formation of the index.

(ii) Type of soil.

(iii) Type of crops to be grown.

Based on this information and the corresponding values of different co-efficients, the index value, Y, a linear combination of X variables is calculated separately for each aspe of health, the type of crop and the type of soil as follows:

$$Y_{ij} = \beta_1 X_{i1j} + \beta_2 X_{i2j} + \beta_3 X_{i3j} + \cdot \cdot \cdot + \beta_p X_{ipj}$$

$$i = 1, 2, \ldots, m$$

$$j = 1, 2, \ldots, n_i$$

where X_{ikj} represents the value of kth variable for the jth item in ith group;

β is the co-efficient variable slope.

This value of Y_{ij} is then compared with the corresponding value of Y^*.

If $Y_{ij} > Y^*$ Wastewater is classified into group 1 i.e. unsuitable

If $Y_{ij} \leqslant Y^*$ It is classified into group 2 i.e. suitable.

Table 4.8

****

SOIL(SANDY)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	pH	Suspended solids (mg/l)	BOD (mg/l)	Gr
BOMBAY(Khar)	5.77	3687.00	6.90	152.00	251.00	1
BOMBAY(Worli)	7.23	2800.00	6.90	124.00	92.00	1
BOMBAY(Versova)	16.22	7047.00	7.60	240.00	150.00	1
MADRAS(Nessapakkam)	4.30	2260.00	7.30	110.00	105.00	1
DELHI(Okhla)	3.22	1060.00	7.50	21.00	15.00	2
JAMSHEDPUR	2.80	500.00	7.30	10.00	12.00	2
BOMBAY(Dadar)	3.31	1250.00	7.20	120.00	110.00	2
PUNE	2.80	520.00	7.30	190.00	100.00	2
HYDERABAD	3.00	958.00	7.50	210.00	100.00	2
MADURAI	3.10	1200.00	7.10	380.00	200.00	2

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1

....

CITIES	VALUE OF Y	CLASSIFICATION
BOMBAY(Khar)	-0.2880796E+03	1
BOMBAY(Worli)	-0.2902973E+03	1
BOMBAY(Versova)	-0.2876732E+03	1
MADRAS(Nessapakkam)	-0.2959438E+03	1

GROUP 2

....

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	-0.3130878E+03	2
JAMSHEDPUR	-0.3189101E+03	2
BOMBAY(Dadar)	-0.3149862E+03	2
PUNE	-0.3287957E+03	2

COEFFICIENT
VARIABLE
SLOPE

1	-0.1163223E+02
2	0.3371802E-01
3	-0.4116526E+02
4	0.8610690E-01
5	-0.2961274E+00

VALUE OF Y-STAR = -0.3046676E+03

* * * * * * * *

****

SOIL(SANDY - LOAM)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	pH	Suspended solids (mg/l)	BOD (mg/l)	Group
BOMBAY(Khar)	5.77	3687.00	6.90	152.00	251.00	1
BOMBAY(Worli)	7.23	2800.00	6.90	124.00	92.00	1
BOMBAY(Versova)	16.22	7047.00	7.60	240.00	150.00	1
MADRAS(Nessapakkam)	4.30	2260.00	7.30	110.00	105.00	1
MADURAI	3.10	1200.00	7.10	380.00	200.00	1
DELHI(Okhla)	3.22	1060.00	7.50	21.00	15.00	2
JAMSHEDPUR	2.80	500.00	7.30	10.00	12.00	2
BOMBAY(Dadar)	3.31	1250.00	7.20	120.00	110.00	2
PUNE	2.80	520.00	7.30	190.00	100.00	2
HYDERABAD	3.00	958.00	7.50	210.00	100.00	2

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1
....

CITIES	VALUE OF Y	CLASSIFICATION
BOMBAY(Khar)	-0.8137713E+03	1
BOMBAY(Worli)	-0.8076185E+03	1
BOMBAY(Versova)	-0.8149219E+03	1
MADRAS(Nessapakkam)	-0.8216736E+03	1
MADURAI	-0.8170563E+03	1

GROUP 2
....

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	-0.8714162E+03	2
JAMSHEDPUR	-0.8856342E+03	2
BOMBAY(Dadar)	-0.8654605E+03	2
PUNE	-0.9832357E+03	2
HYDERABAD	-0.8656597E+03	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	5.	0.
GROUP 2	5.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	-0.3286068E+02
2	0.8676570E-01
3	-0.1137843E+03
4	0.4450738E+00
5	-0.9028417E+00

VALUE OF Y-STAR = -0.8446448E+03

* * * * * * * *

****

SOIL(CLAYEY - LOAM)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	pH	Suspended solids (mg/l)	BOD (mg/l)	Group
BOMBAY(Khar)	5.77	3687.00	6.90	152.00	251.00	1
BOMBAY(Worli)	7.23	2800.00	6.90	124.00	92.00	1
BOMBAY(Versova)	16.22	7047.00	7.60	240.00	150.00	1
HYDERABAD	3.00	958.00	7.50	210.00	100.00	1
MADRAS(Nessapakkam)	4.30	2260.00	7.30	110.00	105.00	1
MADURAI	3.10	1200.00	7.10	380.00	200.00	1
DELHI(Okhla)	3.22	1060.00	7.50	21.00	15.00	2
JAMSHEDPUR	2.80	500.00	7.30	10.00	12.00	2
BOMBAY(Dadar)	3.31	1250.00	7.20	120.00	110.00	2
PUNE	2.80	520.00	7.30	190.00	190.00	2

CLASSIFICATION BASED ON DISCRIMINANT FUNCTION

GROUP 1
....

CITIES	VALUE OF Y	CLASSIFICATION
BOMBAY(Khar)	-0.1557903E+03	1
BOMBAY(Worli)	-0.1566845E+03	1
BOMBAY(Versova)	-0.1533279E+03	1
HYDERABAD	-0.1628306E+03	2
MADRAS(Nessapakkam)	-0.1537437E+03	1
MADURAI	-0.1507790E+03	1

GROUP 2
....

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Okhla)	-0.1673847E+03	2
JAMSHEDPUR	-0.1743416E+03	2
BOMBAY(Dadar)	-0.1677886E+03	2
PUNE	-0.1710105E+03	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	5.	1.
GROUP 2	4.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	-0.1071439E+02
2	0.2664737E-01
3	-0.2135900E+02
4	0.1461533E+00
5	-0.2671530E+00

VALUE OF Y-STAR = -0.1628287E+03

* * * * * * * *

****

SOIL(CLAYEY)

****

CLASSIFICATION BASED ON WEIGHTED MEAN INDEX

CITIES	SAR	EC (m.mhos/cm)	pH	Suspended solids (mg/l)	BOD (mg/l)	Group
BOMBAY(Dadar)	3.31	1250.00	7.20	120.00	110.00	1
BOMBAY(Knar)	5.77	3687.00	6.90	152.00	251.00	1
BOMBAY(Worli)	7.23	2800.00	6.90	124.00	92.00	1
BOMBAY(Versova)	16.22	7047.00	7.60	240.00	150.00	1
HYDERABAD	3.00	958.00	7.50	210.00	100.00	1
MADRAS(Nessapakkam)	4.30	2260.00	7.30	110.00	105.00	1
MADURAI	3.10	1200.00	7.10	380.00	200.00	1
DELHI(Oknla)	3.22	1060.00	7.50	21.00	15.00	2
JAMSHEDPUR	2.80	500.00	7.30	10.00	12.00	2
PUNE	2.80	520.00	7.30	190.00	100.00	2

CLASSIFICAIION BASED ON DISCRIMINANT FUNCTION

GROUP 1
....

CITIES	VALUE OF Y	CLASSIFICATION
BOMBAY(Dadar)	-0.7254623E+02	2
BOMBAY(Knar)	-0.6530715E+02	1
BOMBAY(Worli)	-0.6802205E+02	1
BOMBAY(Versova)	-0.6649579E+02	1
HYDERABAD	-0.7116441E+02	1
MADRAS(Nessapakkam)	-0.6710904E+02	1
MADURAI	-0.6465962E+02	1

GROUP 2
....

CITIES	VALUE OF Y	CLASSIFICATION
DELHI(Oknla)	-0.7401490E+02	2
JAMSHEDPUR	-0.7661357E+02	2
PUNE	-0.7418691E+02	2

SUMMARRY OF ERRORS

	CORRECT	INCORRECT
GROUP 1	6.	1.
GROUP 2	3.	0.

(Contd.)

COEFFICIENT
VARIABLE
SLOPE

1	-0.4238595E+01
2	0.1059271E-01
3	-0.9523050E+01
4	0.5676112E-01
5	-0.9093399E-01

VALUE OF Y-STAR = -0.7141954E+02

* * * * * * * *

This way we shall obtain the results from each sub-case indicating the suitability or otherwise of the given waste-water separately for the type of soil, type of crop to be grown, and health of human/animal consumers and health of workers. These results will be grouped together and presented as one symbol, 'HAWCS'. Each alphabet of the symbol which represents Human consumers' health, Animals health, Workers' health, Crops and Soil respectively, will be subscripted by either of the following:

S - representing suitable

U - representing unsuitable

N - representing not applicable.

For example if a wastewater, which is to be used for growing fodder crops on clayey soil, has been evaluated and classified as 'suitable' for clayey soil and fodder crop but 'unsuitable' for the health of workers and animal consumers, then the result will be presented as:

$$'H_N A_U W_U C_S S_S'$$

H is subscripted by N since the crop grown is fodder and health of human consumers is not affected.

These individual results depicting the suitability for health, crops and soil can now be combined into an overall index $\bar{Y}$. $\bar{Y}$ is worked out by calculating the weighted sum of ratings R, allotted to each value of Y as described below:

$$R = \frac{\text{Value of } Y}{\text{Value of } Y^*} \times 100$$

Different parameters are allotted different weights. The health of workers is allotted the maximum weightage of 0.4.

It is because of their direct contact with the contaminated sewage/soil. Consumers' health (Humans/Animals) next in the priority, gets a weight of 0.3. The crops are placed next in the order, since the quality of crops will affect the economy of the system, and are allotted a weightage of 0.2. The soil gets the least weightage as 0.1 because some of the aspects of the nature like rain, sun and wind etc., and agricultural practices like ploughing and weeding would minimize these effects considerably.

Individual index value Y, its rating R and weight W in each case will be referred to as follows:

H - Y_H, R_H, W_H

A - Y_A, R_A, W_A

W - Y_W, R_W, W_W

C - Y_C, R_C, W_C

S - Y_S, R_S, W_S

Value of $\overline{Y}$ will then be worked out as given below:

$$\overline{Y} = (R_H \cdot W_H) \text{ or } (R_A \cdot W_A) + R_W \cdot W_W + R_C \cdot W_C + R_S \cdot W_S$$

and compared with the value of $\overline{Y^*}$, similarly worked out taking R in each case as 100.

If $\overline{Y} > \overline{Y^*}$, Wastewater is 'unsuitable' for farming

If $\overline{Y} \leqslant \overline{Y^*}$, It is suitable.

4.2. Evaluation of Data Collected:

The data to evolve an index under the present study, were collected from eight cities located in different regions

of the country. Cities visited were (1) Madurai, (2) Madras, (3) Hyderabad, (4) Pune, (5) Bombay, (6) Delhi, (7) Jamshedpur and (8) Kanpur.

Out of these excepting for Bombay, where at present sewage is not used for farming but is under the active consideration of the authorities, at all other places the sewage farming is carried out under the administrative control of civic authorities.

In the case of Bombay, however, wastewater analysis from four different treatment plants has been used as data for the purpose of formulation of the index. Kanpur's wastewater characteristics have not been included as data for this study, because it was found to be more of an industrial than domestic waste; a case which is out of the scope of the present work. This wastewater, however, has been used as a test example to illustrate the method of using this index for evaluation of any wastewater to be used for farming in future.

The wastewater samples from the remaining cities are evaluated for their suitability or otherwise for different aspects of sewage farming. Due to the varying environmental, management and social aspects the results of this evaluation along with the local details of these aspects, each city has been discussed separately according to their geographical location in the country.

MADURAI:

Madurai is the second biggest town of Tamil Nadu with a population of 6.8 lacs (1981 Census). Average annual rain fall here is about 200 cms and the rainy season starts generally by July and goes on till November/December. The ground water table is about 30 to 40 feet below ground level. River Vaigai, which also forms the main source of the water supply, divides the city into two segments, North and South, while flowing from West to East.

Water Resources and Consumption:

Out of the total water supply of 15-16 MGD, about 10 MGD is collected at three different points from river Vaigai into infiltration galleries. It is then collected into the suction wells through gravity, where it is chlorinated and pumped to various localities of the city. All these areas get water for 2 hours/day. There are 2 to 3 community taps per street which get water from various deep bore holes fitted with submergible pumps. In addition there are 1 to 2 hand pumps per street.

Status of Sewerage System:

The area south of Vaigai accommodates the major portion of the population. Habitation on the north side is quite scattered. The existing sewerage system therefore covers only about 35% of the south area. The rest of the area in south and complete area on the north of river either have septic tanks or have dry system of sanitation. The sludge/night soil is collected by lorries under municipal corporation's arrangement and taken to compost fields about 5 km away from the city.

The sewage from various localities (about 7.5 MGD) flows under gravity to 7 subsidiary pumping stations from where it is pumped to the central pumping station. This station diverts 4 MGD of sewage to the sewage farm located at Avaniapuram, at a distance of 8 km and the remaining 3.5 MGD is pumped to an irrigation channel. As per a plan under consideration, the sewage now put into the irrigation channel is supposed to be pumped to north of Vaigai, where along with another 4 MGD of sewage collected from north area, it will be treated at Chakimangalam in 4 oxidation ponds and used for the cultivation of vegetables crops on an area of 2000 acres. Under the first phase of the same planning, the raw sewage presently being used for farming is also to undergo the treatment through aerated lagoons, already under construction near the existing sewage farm.

Status of Sewage Farming:

This farm was started in 1927. Presently it covers an area of 385 acres; out of this 181 acres of land is under direct cultivation of the local body where mostly fodder crops (Guinea grass, etc.) are grown. 3.2 acres of land is leased out to tenements who grow food grain and vegetable crops. Daily about 3.85 MGD raw sewage is supplied to the farm. A noteworthy feature about this farm is that provision for adequate drainage has been made by means of under-drains at a depth of 3 feet. These earthen pipes with open joints are of 3" diameter and laid at a distance of 33 feet c/c. Under this arrangement the sewage which gets filtered is collected

through peripherial drains into a sump. This effluent is either used to maintain four fish ponds in the same vicinity or mixed with the influent and re-circulated through the fields. The accumulated sludge on the surface is periodically removed for making composts.

The type of soil within the farm area is mainly clayey loam. The yield of crop grown, i.e., Guinea grass, which was 50 to 60 tons/acre/annum earlier, was reported to be declining gradually. Daily about 24 cart loads of grass of 435 kg each is sold in the market @ Rs. 0.07/kg. The total income from the farm produce, fishery and the lease amount from private cultivators is about Rs. 6.83 lacs against a total expenditure of Rs. 5.78 lacs per annum.

Observations During the Visit:

1. The sewage effluent remains stagnant in certain low lying areas within the grass fields.
2. The area around the farm is full of flies and mosquitoes.
3. The workers' living camp is situated right on the edge of the sewage farm.
4. The area is not fenced and stray animals keep grazing in the fields and keep lying in sewage water accumulated in low lying areas within the fields.
5. Though provided with gum boots/hand gloves, workers seldom use those while working within the fields; they find it more convenient to work without them.
6. The workers draw water from the wells located within the vicinity of the farm, even though arrangements do

exist for supplying drinking water through lorries by the local body.

7. No schedule of irrigation/drying periods is maintained for different plots of land.

8. Aparently the workers as well as the animals fed on farm produce did not show symptoms of any disease but the previous surveys conducted showed high incidence of helminthic infections amongst this population.[7]

Characteristics of Wastewater:

S.No.	Parameters	Characteristics
1.	SAR	3.1
2.	EC (micromhos/cm)	1200
3.	pH	7.1
4.	Suspended solids (mg/l)	380
5.	BOD (mg/l)	200
6.	Chlorides (mg/l)	220
7.	Bicarbonates (mg/l)	245

Evaluation of Wastewater Quality:

It is seen from the results (Tables 4.7 and 4.10) that Madurai's wastewater is classified as suitable for fodder crops and unsuitable for the type of soil farm has i.e. clayey-loam. Since the wastewater used for farming is untreated, it may be taken as unsuitable for the health of workers as well as animal consumers of the farm produce (based on the results in Tables 4.3 and 4.4).

This wastewater thus can be classified as

$$H_N A_U W_U C_S S_U$$

The health aspects being the most important of all we shall first consider the treatment required to improve the biological quality. From the point of workers' health the treatment technologies found suitable, as per, the results of the analysis presented in Table 4.4, are stabilization ponds, aerated lagoons, land filtration, activated sludge process, and oxidation ditch. The results from Table 4.3 further show that the same treatment systems shall also be able to produce an effluent which is suitable for the health of animals consuming the grown fodder.

The values of Y_S (Table 4.10) for Madurai water is (-)150.7790 against the Y_S^* value of (-)162.8287 for clayey loam soil.

The characteristics of wastewater affecting soil are SAR, EC, pH, SS and BOD. Out of these SS and BOD are the only parameters which can be brought under control by any of the biological treatment processes suggested earlier from the health point of view. The present concentrations of SS and BOD are 380 mg/l and 200 mg/l respectively. Any of the suggested treatment systems should be able to bring down these concentrations to about 38 and 60 respectively. With the decreased values of SS and BOD, the revised values of Y_S can be worked out, using the co-efficients given in Table 4.10, as

$$\begin{aligned} Y_S &= -(3.1 \times 10.71439) + (1200 \times 0.02664737) \\ &\quad -(7.1 \times 21.359) + (38 \times 0.1461533) - (60 \times 0.267153) \\ &= -33.21 + 31.98 - 151.64 + 5.55 - 16.03 \\ &= -163.35 \end{aligned}$$

which is less than Y_S^* (- 162.8287) and hence suitable. With this change of treatment process, the wastewater would be reclassified as

$$H_N A_S W_S C_S S_S$$

Recommendations:

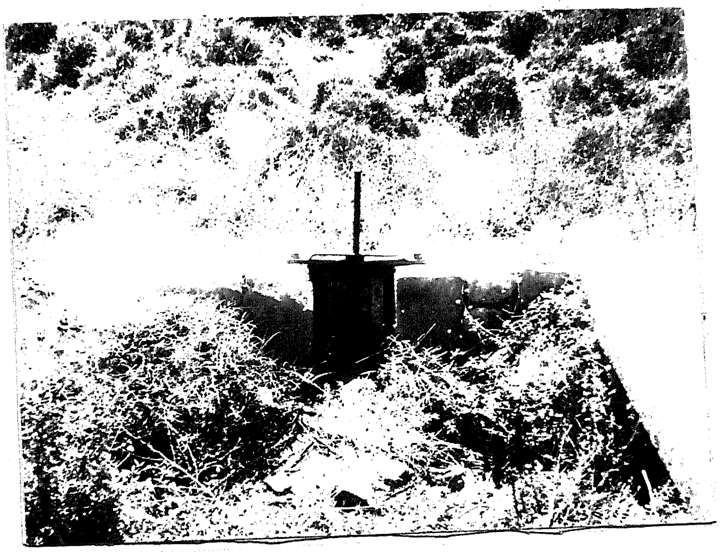
Based on the evaluation of Madurai sewage, the following recommendations, can safely be made.

1. The treatment processes under planning at Madurai, i.e., aerated lagoons and oxidation ponds, as mentioned earlier, once commissioned should be able to produce an effluent suitable for all the aspects of sewage farming considered here.

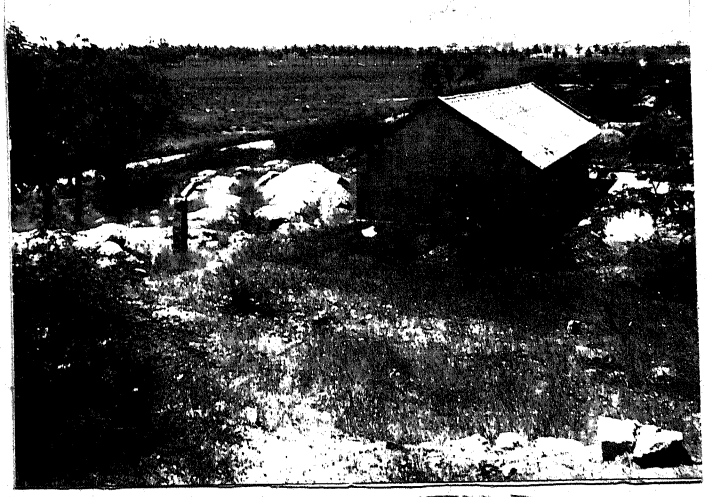
2. Under the changed conditions, part of the farm drainage water which is now recirculated, could instead be used either to irrigate more fish ponds or for growing more crops because of its improved quality and nutritional value.

Certain photographs taken during the visit to sewage farm are presented in Figure 4.1.

Working Conditions at Madurai Sewage Farm

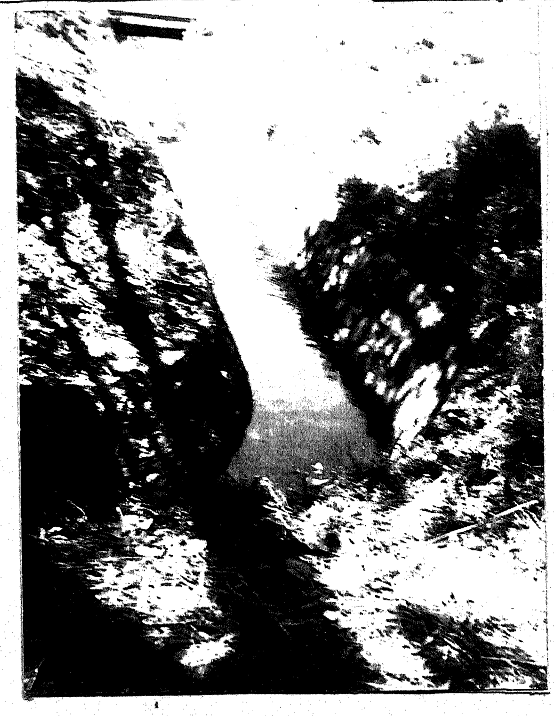


Ill-maintained Influent Channel



Workers Camp in Close Proximity of Sewage Farm

Affected Health of Farm Workers



Effluent Channel

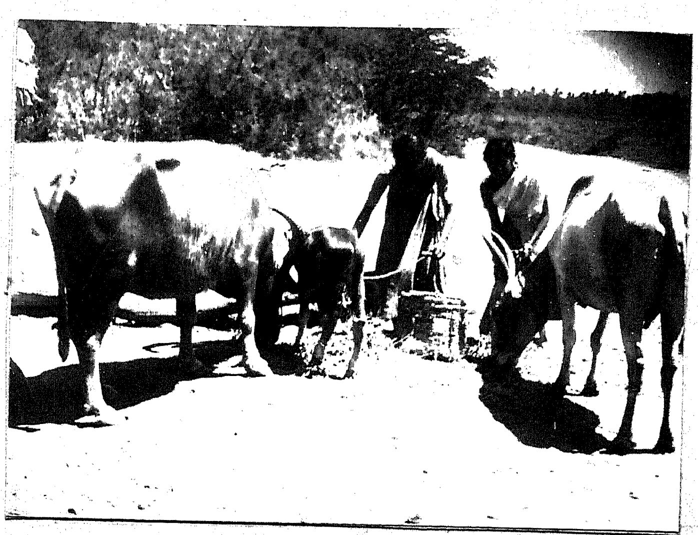
Figure 4.1

Figure 4.1 (Contd.)

Stagnant Sewage in Guniea-grass Fields

Barefeet Working - Convenient but Hazardous

Contaminated Fodder on Way to Market



Milching Cattle Fed on Sewage-Farm Produce

MADRAS:

Madras, the fourth largest city of India and capital of Tamil Nadu is situated on the shores of Bay of Bengal. It covers an area of 1170 sq. kms and its present population is about 43 lacs (1981 Census). The management of water supply and sewerage system is under the newly formed Madras Metropolitan Water Supply and Sewerage Board, whereas the storm drainage and solid waste are still managed by the Municipal Corporation.

Water Resources and Consumption:

A total of 55 MGD of water is supplied by three different lakes at Poondi, Cholavaram and Red hills, from where the water flows down to the water treatment plant at Kilpauk. Here the water is treated by both slow and rapid sand filters and the post-chlorination is done at three different pumping stations. Average per capita water supply is about 15 gallons. There are total of 1,20,000 house service connections and 5850 public stand pipes. In addition to this water supply, the city has 2050 shallow tube wells and 1050 open public wells.

Status of Sewerage System:

Madras City's sewerage system was installed by the then Special Engineer Mr. Madley in the years 1908-1911. Since then the population has increased steadily which has resulted into overflowing of the existing sewers.

Though there are a total of four treatment plants only three are functional. These are Koyambedu, Nessapakkam and Perungudi with a capacity of 7.5 MGD, 5 MGD and 10 MGD respectively. The corresponding treatment systems are bio-filters, activated sludge and primary settling.

The city is divided into five zones for the purpose of collection of sewage. Zone 1 and 2 discharge their wastewater into Kodungaiyur treatment plant which is non-functional. The sewage from Zone 3, is pumped to Koyambedu treatment plant, whereas, from Zone 4, it comes to Nessapakkam. Zone 5's wastewater flows into the treatment plant at Perungudi. Effluent from all these plants is mainly used for irrigation but some of it is discharged into the sea.

There are total of 4 sewage farms under the Sewerage Board's control and located in the vicinity of each treatment plant as follows:

Location	Type of effluent used	Extent of land available	Extent of land under cultivation
Kodungaiyur	Raw sewage	713 acres	489 acres
Koyambedu	Biofilter	294 acres	104 acres
Nesapakkam	Activated sludge	190 acres	22 acres
Perungudi	Primary settled sewage	950 acres	72 acres

The crop grown at all these places is Guinea grass which has a good demand. Average animal income from grass farms is about Rs. 14.0 lacs. The grass cutting and its further disposal is done through contractors who employ their own casual workers. However, watering and other maintenance of the crop is carried out by the Board's workers.

The Nesapakkam treatment plant, which has the most modern technique out of all, for the treatment of wastewater and also its sewage farm has the minimum area under cultivation,

was chosen for the data collection.

This treatment plant was installed in 1976 to cater for a population of 2.5 lacs and covers a drainage area of 13 sq. kms (Zone 4) with the help of 7 pumping stations. It is designed for 5 MGD but the sewage inflow is about 1.5 to 2 MGD. It is situated on the bank of Adyar river and the area occupied is about 3.5 acres. The capital cost of installing this plant in 1976 was Rs. 37.93 lacs and the annual maintenance cost is about Rs. 3.0 lacs.

Sewage farm which is in the premises of the treatment plant covers an area of 190 acres, out of which only 22 acres is under cultivation. This is so because of the limited effluent available for irrigation. The fields are irrigated once a fortnight and harvested every month. The crop gives an yearly revenue of Rs. 1.2 lacs.

Observations During the Visit:

1. The efficiency of the treatment system, which is just about 6 years old has considerably reduced since some of the aerators were found to be out of order. In general most of the plant equipment was found to be badly rusted.
2. Because of the malfunctioning of the system, many a times, the sewage is bypassed and directly supplied for irrigation.
3. As earlier reported by Subramaniam,[53] it was observed that the effluent from sewage plant did not look very much different from raw sewage. It had an objectionable odour and greyish black colour.

4. Many workers reported, of having suffered from various sewage borne diseases during the past for which they are treated by the board's doctors.

5. Though the farm workers have been provided with gum boots etc. none of them was seen using them while working in the fields.

Characteristics of Wastewater:

Nesapakkam plant

S.No.	Parameters	Characteristics Raw	Characteristics Activated sludge effluent
1.	SAR	4.3	4.3
2.	EC (micromhos/cm)	2154.0	2260.0
3.	pH	6.8	7.3
4.	Suspended solids (mg/l)	800.0	110.0
5.	BOD (mg/l)	315.0	105.0
6.	Chlorides (mg/l)	343.0	343.0
7.	Bicarbonates (mg/l)	283.0	283.0

Evaluation of Wastewater Quality:

The wastewater's quality with respect to the type of soil, i.e., clayey-loam and fodder crop grown at Nessapakkam sewage farm has been found to be as

$$H_N A_S W_S C_U S_U$$

As can be seen from the above classification the effluent has not been found to be suitable for fodder crop as well as for clayey-loam soil. It seems to be due to the high salt contents of the water.

The overall index value $\overline{Y}$, to recommend the degree of treatment, if any required, is calculated as follows:

From Tables 4.3, 4.4, 4.7 and 4.10,

$$Y_A = 0.1409890 \quad \text{and} \quad Y_A^* = 0.4503814$$

$$Y_W = 0.3195076 \quad \text{and} \quad Y_W^* = 1.458271$$

$$Y_C = 6.335702 \quad \text{and} \quad Y_C^* = 5.931810$$

$$Y_S = -153.7437 \quad \text{and} \quad Y_S^* = -162.8287$$

The different ratings for these values of Y_S will be

$$R_A = \frac{Y_A}{Y_A^*} \times 100 = \frac{0.1409890}{0.4503814} \times 100 = 3130$$

$$R_W = \frac{Y_W}{Y_W^*} \times 100 = \frac{0.3195076}{1.458271} \times 100 = 21.91$$

$$R_C = \frac{Y_C}{Y_C^*} \times 100 = \frac{6.335702}{5.931810} \times 100 = 106.81$$

$$R_S = \frac{Y_S}{Y_S^*} \times 100 = -\frac{153.7437}{162.8287} \times 100 = -94.42$$

Weights W_A, W_W, W_C and W_S being 0.3, 0.4, 0.2 and 0.1 respectively the value of $\overline{Y}$ will be

$$\overline{Y} = R_A \cdot W_W + R_W \cdot W_W + R_C \cdot W_C + R_S \cdot W_S$$

$$= (31.30 \times 0.3) + (21.91 \times 0.4) + (106.81 \times 0.2)$$

$$- (94.42 \times 0.1)$$

$$= 9.39 + 8.764 + 21.36 - 9.44 = 30.06$$

$$Y^* = (100 \times 0.3) + (100 \times 0.4) + (100 \times 0.2) - (100 \times 0.1)$$

$$= 30 + 40 + 20 - 10 = 80$$

$$30.06 < 80 \quad \text{i.e.} \quad \overline{Y} < Y^* \quad \text{hence suitable.}$$

Recommendations:

Activated sludge effluent which though was not found suitable for crops and soil individually, has met the requirements of accumulative index value Y* and got itself reclassified as suitable mainly because of its good bacteriological quality. Still to avoid any long term effects on the soil and yield of crops, the best solution would be to dilute this effluent with a water having less salt content. But considering the constraints of limited water availability at Madras, it is not being recommended. The present practice may continue with better management of farm activities and improved efficiency of the plant, which at present is working at a much lesser efficiency than the rated one, to reduce the long term effects on soil and crops.

HYDERABAD:

The city of Hyderabad is the fifth largest city of India with its present population of 23 lacs (1981 Ceusus). It also includes the twin city of Secunderabad, which forms part of Hyderabad as per as the provision of water supply and sewerage system are concerned. The river Musi forms the main valley and divides the city into two portions. An annual rainfall of about 65 cms, mainly spread over from May to October has normally been recorded. The ground water table varies from a depth of 10 to 60 feet.

Water Resources and Consumption:

Three different reservoirs namely Osman Sagar, Himayat Sagar and Manjeera form the major sources of the city's water supply, contributing 28 MGD, 22 MGD and 49 MGD respectively. Thus the total demand of 100 MGD of whole of the population is met by these sources only. The various localities are supplied water twice a day. The raw water is subjected to coagulation flocculation, rapid filteration and post-chlorination before it is supplied to consumers.

Status of Sewerage System:

The sewerage scheme was started in 1931 to serve an area of 33 sq. miles with a population of4.68 Lacs. Presently only 40 to 45% of the total population is covered by the sewerage scheme. The sewage is collected from different parts of the city and discharged into two main intercepting sewers which run along either bank of the River Musi. The north intercepting sewer is 4 kms long. The south intercepting sewer is

syphon joins the north intercepting sewer. From this junction it is called the Outfall sewer and flows to the Disposal works. The Outfall sewer is about 3.4 kms long upto the Treatment Plant, where the sewage after partial treatment in septic tanks and dilution with fresh water is carried in a lined channel and given out for irrigation.

The purification plant is situated on the left bank of the river Musi. It was designed for a population of 4.68 Lacs which is now over 22 Lacs. Nearly 20 MGD of sewage is treated and effluent supplied for irrigation. Remaining 27 million gallons of sewage is bypassed due to incapability of the plant to accommodate the whole quantity. A weir to discharge directly into the river any excess flow from the Outfall sever is also provided within the inlet chamber.

<u>Status of Sewage Farming</u>:

About 20 million gallons of sewage effluent from the treatment plant after dilution with fresh water drawn from a water channel, is supplied to different farmers for irrigation. The dilution is carried out based on the requirement of the farmers and the availability of fresh water in the channel. The area under cultivation is about 2000 acres and a revenue of Rs. 60,000 collected by the Revenue Department every year.

The crops grown by different farmers are fodder crops mainly the Guinea grass. The type of soil generally is clayey-loam. The effluent when not required for irrigation is disposed off into river Musi.

Observations During the Visit:

1. The total sewage let into the treatment plant everyday is much more than its designed capacity and hence most of it is bypassed into the irrigation channel directly from grit chambers.
2. The so-called 'fresh water' drawn from a channel and used for dilution is as contaminated as the effluent itself, because of considerable amount of wastewater let into it on the upstream side.
3. Various farm workers complained of the parasitic infections quite prevalent amongst them.
4. The fodder is sold in the city for animal consumption but no information could be obtained on the health status of these animals.

Characteristics of Wastewater:

S.No.	Parameters	Characteristics	
		Raw sewage	Septic tank (Diluted) effluent
1.	SAR	3.5	3.0
2.	EC (micromhos/cm)	1500	958
3.	pH	7.4	7.5
4.	Suspended solids (mg/l)	480	210
5.	BOD (mg/l)	310	100
6.	Chlorides (mg/l)	172	82
7.	Bicarbonates (mg/l)	380	280

Evaluation of Wastewater Quality:

The wastewater has been classified as

$$'H_N A_U W_U C_S S_S$$

which shows that dilution of plant effluent with fresh water makes it suitable for crops and soil but its biological quality which has been considered to be that of a septic tank effluent does not come up to the mark. To quantify its overall effect we calculate the value of $\bar{Y}$, the accumulative index.

From Tables 4.3, 4.4, 4.7 and 4.10 we get the different values of Y and Y* as

$$Y_A = 2.349816 \quad \text{and} \quad Y_A^* = 0.4503814$$

$$Y_W = 4.092031 \quad \text{and} \quad Y_W^* = 1.458271$$

$$Y_C = 3.208045 \quad \text{and} \quad Y_C^* = 5.931810$$

$$Y_S = -162.8306 \quad \text{and} \quad Y_S^* = -162.8287$$

Accordingly the ratings for these values will be

$$R_A = \frac{2.349816}{0.4503814} \times 100 = 521.74$$

$$R_W = \frac{4.092031}{1.458271} \times 100 = 280.61$$

$$R_C = \frac{3.208045}{5.931810} \times 100 = 54.08$$

$$R_S = -\frac{162.8306}{162.8287} \times 100 = 100.00$$

$$\bar{Y} = R_A.W_A + R_W.W_W + R_C.W_C + R_S.W_S$$

$$= (521.74 \times 0.3) + (280.61 \times 0.4) + (54.08 \times 0.2) - (100 \times 0.1)$$

$$= 156.52 + 112.24 + 10.81 - 10$$

$$= 269.57$$

$$\overline{Y^*} = (100 \times 0.3) + (100 \times 0.4) + (100 \times 0.2) - (100 \times 0.1)$$

$$= 30 + 40 + 20 - 10 = 80$$

$$269.57 > 80 \quad \text{i.e.} \quad \overline{Y} > \overline{Y^*}, \text{ hence unsuitable.}$$

The above results show that even though the wastewater has been classified as suitable for crops and soil individually, its value is far away from the standards of $\overline{Y^*}$. This is because of its unsuitability for the health aspects. For this any of the treatment processes found suitable in Tables 4.3 and 4.4 should be able to improve the present quality of effluent. However, none of these processes will be able to reduce the high salt contents of raw sewage which are presently being taken care of by dilution.

Recommendations:

The planned activated sludge plant, as mentioned previously, when installed at the same treatment site, should be able to produce an effluent which meets the biological requirements of the index.

However, the salt contents of raw sewage, are unlikely to be reduced with the changed treatment process. Under those conditions the effluent may not be reclassified as 'suitable' for crops and the practice of dilution may have to be continued even after the installation of the new plant. The quality of the dilution water should also be monitored and kept under control especially its salt contents.

PUNE:

Pune, the metropolis city of Maharashtra is situated 200 km south of Bombay. Its total population is about 18 Lacs (1981 Census). The average rainfall is 70 cms, the rainy season being from June to September. Although due to rapid industrialization the city has acquired a modern look, certain areas within the city are still holding on to the old traditions, and the latest mode of civic amenities has not affected them.

Water Resources and Consumption:

The complete water requirement of the city is met by the Khadakwasla reservoir, where the water gets accumulated through two different rivers, Mula and Mutha. Water is pumped from there to the water-treatment plant where after undergoing the conventional treatment it is supplied to the consumers. Many new localities which have come up in the recent times have their independent water supply arrangements through tube wells, etc.

Status of Sewerage System:

The sewerage scheme at Pune was started around 1930. Sewage from different parts of the city (about 12 MGD) is collected through various trunk sewers leading to Bahiroba Pumping Station whereas at many places it is also discharged directly into the river Mula-Mutha flowing through the city.

From the central pumping station where the sewage is also subjected to primary sedimentation, it is pumped to the disposal point at Hadapsar, situated 5 km away. At Hadapsar

it is mixed with the canal water and supplied to the fields for irrigation.

Status of Sewage Farming:

The total area covered by sewage irrigation is about 800 acres which belongs to different farmers. Generally, the type of soil is clayey-loam or clayey. The crops grown vary from farm to farm depending on the individual choice of each farmer. Generally, different variety of vegetables and sugar-cane are preferred because of their good economic returns. However, many farmers grow only fodder crops.

Observations During the Visit:

1. While plucking the vegetables especially those with rough surfaces no precautions are taken to avoid their direct contact with the still wet soil.
2. Excepting for the odour problems and non-aesthetic conditions the farmers were found to be unaware of the numerous health hazards related to sewage farming and hence do not take any precautionary measures.
3. The villagers draw water from wells located in the vicinity of sewage farms, which are liable to be contaminated, since the water level in the wells was found to be quite high.
4. When adequate water is not available in the canal the sewage is applied as it is without any dilution.

Characteristics of Wastewater:

S.No.	Parameters	Characteristics	
		Raw sewage	Effluent after 1:1 dilution
1.	SAR	-	2.8
2.	EC (micromhos/cm)	930	520
3.	pH	7.2	7.3
4.	Suspended solids (mg/l)	400	190
5.	BOD (mg/l)	270	100
6.	Chlorides (mg/l)	90	52
7.	Bicarbonates(mg/l)	180	162

Evaluation of Wastewater Quality:

Data, required for evaluation are as follows:

1. Type of soil - Clayey
2. Type of crops grown - Vegetables, field and fodder
3. Type of treatment - Primary sedimentation and 50% dilution

Based on the above data, the wastewater has been classified as $H_U A_S W_U C_S S_S$ vide Tables 4.1, 4.3, 4.4, 4.5 and 4.11.

The above analysis has found the diluted settled sewage of Pune suitable for the crops, soil and the health of animal consumers but unsuitable for the health of workers and human consumers. Both being the important aspects the wastewater will have to be further treated. To recommend the degree of such a treatment required, the evaluation of its overall suitability is carried out by calculating the value of $\bar{Y}$.

From Tables 4.1, 4.4, 4.5 and 4.11,

$Y_H = 0.9786839$ and $Y_H^* = 0.6503412$

$Y_W = 4.499268$ and $Y_W^* = 1.458271$

$Y_C = 25.80037$ and $Y_C^* = 41.22665$

$Y_S = -74.18691$ and $Y_S^* = -71.41954$

Corresponding values of ratings will be

$$R_H = \frac{0.9786639}{0.6503412} \times 100 = 150.48$$

$$R_W = \frac{4.499268}{1.458271} \times 100 = 300.85$$

$$R_C = \frac{25.80037}{41.22665} \times 100 = 62.58$$

$$R_S = -\frac{74.18691}{71.41954} \times 100 = -103.87$$

Weights W_H, W_W, W_C and W_S being 0.3, 0.4, 0.2 and 0.1 respectively.

$$\begin{aligned} \overline{Y} &= R_H.W_H + R_W.W_W + R_C.W_C + R_S.W_S \\ &= (150.48 \times 0.3) + (300.85 \times 0.4) + (62.58 \times 0.2) \\ &\quad - (103.87 \times 0.1) \\ &= 45.14 + 120.34 + 12.52 - 10.39 \\ &= 167.61 \end{aligned}$$

$$\begin{aligned} \overline{Y^*} &= (100 \times 0.3) + (100 \times 0.4) + (100 \times 0.2) - (100 \times 0.1) \\ &= 30 + 40 + 20 - 10 = 80 \end{aligned}$$

$167.61 > 80$ i.e. $\overline{Y} > \overline{Y^*}$, hence unsuitable.

Recommendations:

Any of the treatments, found suitable for the health of human consumers and farm workers (Table 4.1) can be applied

to bring down the value of $\bar{Y}$ less than 80, which at present is 167.61 mainly because of its high rating in the case of worker's health.

From the results of evaluation for worker's health (Table 4.4) the chlorination of raw sewage has been classified as 'unsuitable'. If the details of such evaluation are reviewed it can be seen that this may be because of the concentration of hookworm ova present in such an effluent. Since the wastewater at Pune is already subjected to Primary sedimentation, which is quite effective in removing hookworm ova, the chlorination of the settled sewage should be able to meet the requirement and can also be considered along with the other recommended treatment processes.

BOMBAY:

A city with a population of about 76 Lacs (1981 Census) is divided into 13 drainage zones. Sewage from these zones is collected at different points for treatment. Secondary treatment facilities exist only at Colaba, Banganga and Dadar Treatment Plants. Others have only primary treatment systems.

Domestic sewage generation rate varies from 24 - 60 gallons per capita per day. The total of about 1230 industries are also contributing a significant wastewater load to the system.

Because of the increasing sea-water pollution the authorities are planning to use the effluent from different treatment plants for irrigating the agricultural land available on the outskirts of Bombay.

Observations During the Visit:

1. Though at present no sewage farming is carried out by the authorities, various plots of land flooded with sewage along the trunk sewers are seen flourishing with vegetables like spinach, raddish and cabbage while travelling in a local train. This seems to be the result of pilferage of raw sewage from the sewers passing through the various slums.
2. The capacity of all the treatment plants is insufficient for the present influent and hence most of the flow is bypassed and discharged into the Arabian Sea without treatment.

Characteristics of Wastewater:

S.No.	Parameters	Effluent characteristics Dadar	Khar	Worli	Versova
1.	SAR	3.31	5.77	7.23	16.22
2.	EC (micromhos/cm)	1250	3687	2800	7047
3.	pH	7.20	6.9	6.9	7.6
4.	Suspended solids(mg/l)	120	152	124	240
5.	BOD (mg/l)	110	251	92	150
6.	Chlorides (mg/l)	268	900	856	1750
7.	Bicarbonates (mg/l)	341	264	321	257

Evaluation of Wastewater Quality:

Excepting for effluent from Dadar none of the other three plants effluent has been classified as suitable for any type of crop or soil especially the Bombay's clayey/clayey loam soil.

Dadar's effluent has been found suitable only for soil but unsuitable for all types of crops. Since the treatment given is activated sludge process the effluent can be classified as $H_S A_S W_S C_U S_S$.

This wastewater though found to be unsuitable for crops, will be able to meet the requirements of overall index value $\overline{Y^*}$, because of its suitability in all other fields and hence need not be subjected to any further treatment.

Recommendations:

1. Sewage effluents from different plants at Bombay contain relatively higher dissolved solids and have a higher sodium adsorption ratio. These could only be used for

irrigation of salt tolerant crops like fodder, etc. after undergoing the required modifications since none of the biological processes shall be able to reduce much of their concentration.

2. Most of these plants have limited capacity and will have to be expanded to treat the increasing influent, if effluent is planned to be used for irrigation. As, this irrigation of land is being planned outside Bombay, on Bombay-Ahmedabad route, where sufficient amount of land can be obtained at comparatively cheaper rates, it is recommended that the raw sewage directly be carried to the outskirts and treated there either through land filteration or oxidation ponds followed by maturation ponds; the systems found to be cheaper and more efficient in producing an effluent required for farming.

DELHI:

Delhi, the capital city of India, is a harmonous blend of the old and new. Same is true for its civic amenities also. Its water supply systems vary from round the clock tap water to community wells and hand pumps; its waste collection and disposal system though provides the major portion of its total population of 62.5 Lacs (1981 Census) with the modern sewerage system, deprives many of this facility who still are subjected to the dry system of sanitation. Annual rainfall of the city recorded during 1981-82 is 60 cms, the rainy season being from June to September. The ground water has been found to be 8 to 10 feet below the ground level. River Yamuna flows through the city from North to South.

Water Resources and Consumption:

The major water resources tapped by the civic authorities are: (1) Yamuna river at two places, Wazirabad and Okhla, with an intake of 180 MGD and 6 MGD respectively; (2) Western Yamuna canal at Hyderpur (100 MGD); (3) Rainy well waters in river basin, 8 Nos. (20 MGD); (4) Various tube wells within the city.

The water treatment plants exist at Wazirabad and Hyderpur, where the process includes rapid-sand filtration followed by chlorination.

Status of Sewerage System:

There are total of 4 trunk sewers which collect the sewage from different parts of the city. One, called the North Trunk takes the sewage through a pumping station to North sewage treatment plant; the second, called West Trunk

flows till the Keshopur sewage treatment plant and the other two bring the sewage, through two pumping stations, to Okhla treatment plant.

Okhla treatment plant gets the sewage from a radius of 15 kms. Total sewage pumped into Okhla plant is 93 MGD. This plant has a system of activated sludge process which was installed in 1937 and renovated in 1963, two bio-filters, each of 10 MGD capacity and a 30 MGD plant with two clarifiers. Daily about 25 to 30 million gallons of sewage is treated through activated sludge plant against the design capacity of 18 MGD. The effluent from both the systems is supplied for irrigation to adjoining private farmers. Out of the total of about 90 MGD sewage flowing in, 60 MGD is supplied to farmers; 30 MGD plant effluent and 30 MGD after primary sedimentation. Remaining 30 MGD is let into the nearby canal called Agra canal.

The other two treatment plants are Keshopur and North Treatment plant. Keshopur has two treatment systems, activated sludge process with a capacity of 12 MGD and oxidation ditch treating 20 MGD. The North plant has bio-filters. The effluent from these plants also is supplied to farmers for irrigation.

Okhla treatment plant also accommodates the anaerobic digesters where 3 Lacs gallons of sludge is fed for digestion every day. These digesters though have a capacity to produce 6 Lacs cft/day of cooking gas but due to lesser demand produce only 3 Lacs cft. This gas is supplied to 700 domestic consumers @ Rs.18 per months for each family of 5 members. Daily

sludge production from these digesters is about 180 tonnes which is sold @ Rs. 100 per truck of 3 tonnes each.

Status of Sewage Farming:

Though, there is no sewage farm manned by the civic authorities, still almost all the effluent from different treatment plants is used for irrigation. It is supplied to the private owners of the adjoining agricultural fields, under the arrangements of Minor-Irrigation Department of Delhi Administration.

At Okhla, 25-30 MGD of activated sludge effluent, 18 MGD of trickling-filter effluent and 25-30 MGD from clarifiers after primary sedimentation, is all let out in a common single channel, which takes it to various fields. The total land covered by irrigation is about 2900 acres. The type of soil generally is sandy-loam. The crops grown by different farmers are cereals, vegetables and flowers mainly rose and merry gold.

Same is the case at the other two treatment plants; at Wazirabad, the effluent from activated sludge process and oxidation ditch is mixed up and supplied for irrigation; at North plant the effluent from biofilters is straight supplied to the private farmers.

Observations During the Visit:

1. The influent flowing into various treatment plants is more than their design capacity and hence the quality of effluent let into the irrigation channels, at times is as bad as raw sewage itself.

2. The effluent from different treatment systems, with

different degree of treatment, is mixed up together in the same channel leading to the agricultural fields.

3. There is no check over the farmers, on the type of crops to be grown with the quality of effluent being supplied, who prefer to grow green leafy vegetables which give them higher yields.
4. Effects on the health of farmers have not been monitored.
5. Since farmers have to pay for it, only the required quantity of effluent is drawn by them and hence no water-logging was noticed anywhere in the fields.

Characteristics of Wastewater:

Okhla Plant

S. No.	Parameters	Characteristics			
			Effluent		
		Raw	Activated sludge	Trickling filter	Primary sedimentation
1.	SAR	3.40	3.22	3.23	3.3
2.	EC (micromhos/cm)	1200	1060	1080	1120
3.	pH	7.4	7.5	7.5	7.4
4.	Suspended solids (mg/l)	375	21	50	102
5.	BOD (mg/l)	190	15	40	76
6.	Chlorides (mg/l)	160	155	155	158
7.	Bicarbonates (mg/l)	352	350	352	352

Evaluation of Wastewater Quality:

Though, the effluent from all the three treatment systems is mixed before their application to crops, for the purpose of

this study activated sludge effluent has been taken for evaluation.

This effluent has been evaluated for its use on sandy-loam soil for growing vegetable crops. As seen from Tables 4.1, 4.4, 4.5 and 4.9, Delhi wastewater can be classified as

$$H_S A_N W_S C_U S_S$$

This classification shows that the effluent which is suitable for health and soil conditions does not meet the requirements of vegetable crops. From this result it can be concluded that this is mainly so because of the high concentrations of parameters affecting crops which have not reduced much even after undergoing the activated sludge process. This can possibly be achieved by diluting the effluent with fresh water. Before this is finally recommended, its overall suitability by calculating the value of $\bar{Y}$ can be ascertained.

From Tables 4.1, 4.4, 4.5 and 4.9 the values of Y and Y* are as follows:

$Y_H = 0.2536077$ and $Y^*_H = 0.6503412$

$Y_W = 0.3195076$ and $Y^*_W = 1.458271$

$Y_C = 61.63181$ and $Y^*_C = 41.22665$

$Y_S = -871.4162$ and $Y^*_S = -844.6448$

Corresponding values of ratings will be

$$R_H = \frac{0.2536077}{0.6503412} \times 100 = 39.00$$

$$R_W = \frac{0.3195076}{1.458271} \times 100 = 21.91$$

$$R_C = \frac{61.63181}{41.22665} \times 100 = 149.50$$

$$R_S = -\frac{871.4162}{844.6448} \times 100 = -103.17$$

Weights W_H, W_W, W_C and W_S being 0.3, 0.4, 0.2 and 0.1 respectively value of $\overline{Y}$ will be

$$\overline{Y} = R_H.W_H + R_W.W_W + R_C.W_C + R_S.W_S$$

$$= (39 \times 0.3) + (21.91 \times 0.4) + (149.5 \times 0.2) - (103.17$$
$$- (103.17 \times 0.1)$$

$$= 11.7 + 8.76 + 29.9 - 10.32$$

$$= 40.04$$

$$\overline{Y^*} = (100 \times 0.3) + (100 \times 0.4) + (100 \times 0.2) - (100 \times 0.1)$$

$$= 30 + 40 + 20 - 10 = 80$$

$40.04 < 80$ i.e. $\overline{Y} < \overline{Y^*}$, hence suitable.

This shows that the wastewater even though was not found suitable for crops and needed further dilution, has met the requirement of overall quality index value Y*. In view of this no further treatment is being recommended.

Recommendations:

As for the evaluation, only activated sludge effluent has been considered but actually it is the mixture of three different effluents (other two being from the trickling filter and primary sedimentation plants) which is let into the irrigation channel going out of the Okhla treatment plant.

Since the effluent from other two plants has not been found to be suitable for the health of workers/human consumers, it is recommended that either they should be further treated to match the index value or should not be let into the same channel leading to the farms growing vegetable crops.

JAMSHEDPUR:

Jamshedpur, now a famous steel city of Bihar, came up in 1907. The land at this place rich in iron-ore was acquired by Jamshedji Tata, the founder of the Tata Group of Industries, who later set up the famous Tata Iron and Steel Company (TISCO) here. The peculiarity about this town is that it is completely managed by this private company and no civic body or governmental authorities are involved in any way. This is situated on the bank of river Subernarekha, which is also the major source of its water supply. It has a population of approximately 4 Lacs (1981 Census). Average annual rainfall is about 120 cms. The rains start around middle of June and last till the end of August. The ground water table is from 25 to 120 feet below the ground level.

Water Resources and Consumption:

The raw water resources for drinking water supply are, an impounded reservoir at Dimna at a height (530'), nearly 8 kms away from the city and the Subernarekha river. Because of the limited capacity of Dimna reservoir, i.e., 8000 million gallons, water is drawn from there only for 6 months, i.e., April to September and for the remaining period of the year, river water is used.

The water from Dimna reservoir flows under gravity to the treatment plant and from river it is pumped through river pump house. 27 MGD of water is treated and supplied to the town apart from the water used for factory. The daily water consumption is about 60-65 gallons/capita through a 6 hourly supply, two hours each in the morning, midday, and evening.

The water supply has been reported to be free from turbidity, colour, odour or pathogens. The water treatment processes include pre-chlorination, coagulation and flocculation, filtration and post-chlorination. The incidence of water borne diseases is claimed as 0.5 per 1000 population which seems to be the lowest in the country.

Status of Sewerage System:

The sewage from the town with a total length of sewers of 314 kms, is collected at 5 pumping stations from where it is pumped to a central pumping station which is about 2 kms away from the sewage treatment plant installed in 1944. The treatment system is the activated sludge process with a capacity of 4 MGD. With a water supply of 28 MGD, only 4 MGD of sewage is diverted for treatment and rest is disposed off into the river without any treatment. Out of these 4 MGD, not more than 1 to 2 MGD reaches the plant. The remaining is either pilfered by local farmers, who have small agricultural plots enroute or leaks out through defective sewer joints.

The effluent from this plant flows under gravity to the adjoining sewage farm. The sludge gets collected in two consolidation tanks, each of 40,000 gallons capacity, from where about 50% supernatant flows back to the system and remaining goes into a two stage digester. After digestion the sludge is passed on to the drying beds. The yearly output of digested sludge is al

contents as N:P:K have been

Status of Sewage Farm:

The sewage farm, situated next to the treatment plant, gets an average of 1 to 1.5 MGD of its effluent against its requirement of 3-4 MGD. This farm also is manned by TISCO authorities. The type of soil in the farm which covers an area of 165 acres is clayey loam. Out of this, 65 acres are under perinial crops, i.e., Napier grass, Para grass and Guinea grass, another 60 acres have annual crops like maize, cow-pea and barseem and remaining 40 acres land is not under cultivation being a low lying area. It is now being filled up with solid waste from town, to be used for agriculture later.

All the crops grown are used only as fodder for animals. The total output of complete fodder is about 20-30 tonnes/day. Out of this, 10-12 tonnes is used for the Company's own dairy/ poultry farm, which are also situated next to the sewage farm, and remaining is sold out @ Rs. 70 to 95 per tonne. The Napier grass which is also known as Elephant grass is found to be the most nutritious amongst all the grasses with 10 to 12% protein content. It has a total life of 10 to 15 years and is ready for harvesting after every 60 days. It is irrigated after every 15 days. Para grass in contrast needs standing water and is harvested every 25-35 days. Guinea grass has not found much favour, however, and is being discarded slowly. The other annual crops like maize, cow-pea and barseem, grown round the year, give 3 to 4 cuttings. These are irrigated after every 10 to 15 days.

There are about 350 cattle heads in the dairy farm which are mainly fed on the farm grown fodder. The daily milk

production of about 700 litres is supplied to Company's own employees. A poultry farm is also being run by the Company, which too utilises the foliage of farm produce. In addition to this, there are two fish ponds, each with an area of 2-3 acres, located within the farm premises. The sewage effluent, when not being used for irrigation is diverted to these ponds, Fishing is restricted to the Angling Club members of the Company.

Observations During the Visit:

1. Whether it was water supply or sewage treatment/disposal, the touch of good management could be felt in every field.
2. The total revenue earned out of the product sale is about 47 Lacs per annum against a recurring expenditure of about Rs. 62 Lacs. This is mainly so, because the products of dairy and poultry are sold at subsidized rates to the Company's own employees.
3. The transport system of sewage from town to the treatment plant, however, showed some slackness on the part of supervisory staff since only half of the total sewage reaches the treatment plant.
4. At the sewage farm, which is looked after by an agriculture specialist, the required irrigation schedule is followed and no extra effluent is found to be accumulated within the fields.
5. The farm workers are employed on daily wages, through a contractor, who keep changing from time to time.
6. No ill-effects on the health of these workers have ever

been observed during their regular medical examination by the Company doctors.

7. The animals at dairy farm also are examined from time to time by the veterinary doctor and have never been found to be suffering from any sewage-borne diseases.

Characteristics of Wastewater

S.No.	Parameters	Characteristics	
		Raw sewage	Activated sludge effluent
1.	SAR	3.0	2.8
2.	EC (micromhos/cm)	545	500
3.	pH	7.2	7.3
4.	Suspended solids (mg/l)	320	10
5.	BOD (mg/l)	125	12
6.	Chlorides (mg/l)	36	34
7.	Bicarbonates (mg/l)	180	172

Evaluation of Wastewater Quality:

Activated sludge effluent at Jamshedpur which is used for the growth of fodder crops on clayey-loam soil has been classified (Tables 4.2, 4.4, 4.7 and 4.10) as:

$$H_N A_S W_S C_S S_S$$

Since the wastewater has been classified in all the cases as 'suitable' it is not checked for its overall index value $\overline{Y}$ which will certainly be less than $\overline{Y^*}$ and hence needs no further treatment.

Recommendations:

Jamshedpur wastewater has been classified as suitable even for the growth of vegetable crops both from health and crops point of view. On the basis of these results and the observations made during the visit about the management practices, this effluent can safely be recommended for growing cereal and vegetable crops if required.

The arrangements however be made to ensure that the complete sewage be treated and used for irrigation instead of discharging untreated sewage into the river, its pilferage and the leakage on the way to treatment plant should also be curbed by certain administrative measures.

During the visit to sewage farm at Jamshedpur, a few photographs depicting the conditions prevalent were taken which are presented in Figure 4.2.

Workers in Effluent Stagnant Fields of Para Grass

Above Ground Level Cutting of Napier Grass

Farm Managers in Kitchen Garden

Boundary Wall between Sewage Farm and Habitation

Wastewater Fish Pond

KANPUR:

Kanpur is one of the five major cities of Uttar Pradesh and is the largest industrial centre of the state. It is situated on the right bank of river Ganges. Another river Pandu flows on its south as well as east. It covers an area of 261.59 sq. kms supporting a population of 16.85 Lacs (1981 Census). It's climate is subtropical with an annual rainfall of about 88 cms. Rainy season starts in July and ends in September. The subsoil water level varies from a depth of 15 to 32 feet within the city.

Water Resources and Consumption:

The major source of water for Kanpur is river Ganges which supplies about 83 MGD of water. The remaining 32 MGD of an overall demand of 115 MGD is met by 35 tube-wells recently installed in various parts of the city. The water from river Ganges is drawn in two ways. About 75% is pumped directly from the river into the water works treatment plant and the remaining is drawn and brought to the plant from Ganges canal.

The water is given conventional treatment and pumped into various reservoirs. The only peculiarity of the treatment plant being its two dual media (coal and sand) rapid gravity filters which are found to be functioning better than the other slow and rapid sand filters at the plant.

The water from tube-wells is mixed with the treated water in different reservoirs. The average daily consumption is about 20-25 gallons per capita with a round the clock supply to old zones and timely supply during morning, midday and

evening for five, two and five hours respectively to the new zones.

Status of Sewerage System:

Origin of the drainage system in Kanpur dates back to 1870 but the sewerage scheme was completed by 1904. Since then, though the population has increased manifolds, no change in the carrying capacity of the sewers has taken place. With the exception of a few, which dispose of their waste directly into Ganges, most of the tanneries as well as several other industries discharge their waste into the same sewers. Due to all these reasons a major portion of the sewage overflows into different nullahs passing through the city which ultimately end up into river Ganges. The remaining sewage, about 40 MGD is collected from different parts of the city and taken to a pumping station at Jajmau, on the bank of the Ganges.

The pumping station pumps the sewage to an irrigation channel leading to the fields for cultivation. A by-pass channel to the river has also been provided. Arrangements at this station exist for pumping-in raw water from the river as well as pumping out the 1:1 mixture of sewage and water for cultivation.

No treatment of sewage, excepting for screening arrangements is provided at the pumping station site. However, many times, since 1945 planning has been carried out to treat the sewage before discharge, but could never be implemented because of paucity of funds. The latest plans under consideration are to treat the water in two ways: Trickling filters for areas with less than two lacs population and Activated sludge

process for areas with a population of more than two lacs. The effluent is to be used for farming, and sludge for digestion and gas production.

Status of Sewage Farming:

In spite of the planning to use the sewage for farming, since the inception of the sewerage scheme, it could only be done in 1950 when 1000 acres of land was accquired by the Development Board and leased out for 7 years. 6 MGD of a total of 12 MGD sewage, from the Jajmau outfall, was used for the purpose.

In 1953 seeing the response of many more farmers it was proposed that the complete sewage be used for agriculture, but to minimise its ill effects it required to be diluted with an equal amount of water drawn from Ganges. To utilize this diluted sewage (24 MGD), the board did not acquire any additional land, but, instead proposed to irrigate an additional area of 3800 acres belonging to private farmers.

At present, though the total incoming sewage has increased to 40 MGD, the required quantity for irrigation has never been able to reach the fields due to the decreased pumping capacity at the Jajmau pumping station.

The wastewater from the pumping station is pumped into a lined channel and supplied to the adjoining fields. Generally, the crops grown by farmers are wheat, paddy and barseem (a fodder crop), who in turn pay the lease amount/revenue to the Municipal Corporation every year.

Observations During the Visit:

1. At Jajmau pumping station four pumps were found to be out of order for more than a year out of a total of eight: six meant for pumping sewage and two for the purpose of drawing raw water for dilution. This has resulted into bypassing of most of the sewage to the river Ganges.
2. For more than four months in a year, due to non-availability of water at the intake point in the river, the sewage is pumped without any dilution to the irrigation channel.
3. The wastewater carried in small earthen channels,running along an approach road was found to be used for washing, etc., by passers by. Children of a nearby school were also seen playing in these channels.
4. The farmers informed when approached of having contacted skin diseases in the initial stages of sewage farming, but presently none had any apparent symptoms.

Characteristics of Wastewater[(a)]:

S.No.	Parameters	Characteristics (Raw)
1.	SAR	3.2
2.	EC (micromhos/cm)	1875
3.	pH	6.5
4.	Suspended solids	706
5.	BOD	270
6.	Chlorides	146
7.	Bicarbonates	340
8.	Copper	4.0
9.	Lead	1.0
10.	Zinc	0.4
11.	Tannin	26

(a) Except for SAR, EC and pH other values are expressed as mg/l.

Evaluation of Wastewater Quality:

Because of the addition of most of the discharge from tanning, textile, electroplating and many other industries the characteristics of the sewage being used for irrigation, are different from the normal domestic sewage. Various trace elements present in sewage are more than the recommended tolerance limits. This waste, which is more industrial than domestic in nature, is beyond the scope of this study, and therefore, is not included as data for the formation of index. However, the wastewater of Kanpur has been used as a test example to illustrate the method of using the wastewater quality index, in future.

Test Example:

Since the type of soil around Jajmau area, the present site of farming, is sandy-loam and crops grown are generally cereals, i.e., field crops, we will evaluate the various characteristics for these and the health aspects of human consumers and farm workers.

We will take the values of co-efficients in each case as derived from the collected data and calculate the corresponding Y values for each case as follows:

Health of Human Consumers (w.r.t. Field Crops) (Ref. Table 4.2)

S. No.	Parameters	Characteristics of raw sewage	Co-efficient
1.	Entericvirus (No./l)	10^6	0.00009901041
2.	*E. coli* (No./l)	10^7	-0.0000001880641
3.	*Ascaris* ova (No./l)	5×10^3	-0.001603908

Value of Y* = 0.05216287

Value of Y_H, therefore, will be

$$= (10^5 \times 0.00009901041) - (10^7 \times 0.0000001880641)$$
$$- (5000 \times 0.001603908)$$
$$= 9.90 - 1.88 - 8.0$$
$$= 0.2 \qquad \text{i.e.} \quad Y_H > Y_H^*, \text{ hence unsuitable.}$$

Health of Workers (Table 4.4):

S. No.	Parameters	Characteristics of raw sewage	Co-efficient
1.	Enteric virus (No./l)	10^6	0.0003800198
2.	*E. coli* (No./l)	10^8	0.000003885600
3.	Amoeba cysts (No./l)	5×10^4	-0.001094983
4.	Hookworm ova (No./l)	2×10^3	0.001968387

Value of $Y_W^* = 1.458271$

$$Y_W^* = (10^5 \times 0.0003800198) + (10^7 \times 0.000003885600)$$
$$- (5 \times 10^4 \times 0.001094983) + (2 \times 10^3 \times 0.001968387)$$
$$= 38.00 + 38.85 - 54.70 + 3.94$$
$$= 26.09 \qquad \text{i.e.} \quad Y_W > Y_W^*, \text{ hence unsuitable.}$$

Field Crops (Table 4.6):

S. No.	Parameters	Characteristics	Co-efficients
1.	SAR	3.2	-1.641028
2.	EC (micromhos/cm)	1875	0.00231812
3.	Chlorides (mg/l)	146	0.008523698
4.	Bicarbonates (mg/l)	340	0.05430746

Value of $Y_C^* = 13.07639$

$$Y_C = -(3.2 \times 1.641028) + (1875 \times 0.00231812)$$
$$+ (146 \times 0.008523698) + (340 \times 0.05430746)$$
$$= -5.25 + 4.35 + 1.24 + 18.46$$
$$= 18.80$$

$18.80 > 13.076$ i.e. $Y_C > Y_C^*$, hence unsuitable.

Sandy-Loam Soil (Table 4.9):

S.No.	Parameters	Characteristics	Co-efficients
1.	SAR	3.2	-32.86008
2.	EC (micromhos/cm)	1875	0.0867657
3.	pH	6.5	-113.7843
4.	Suspended solids (mg/l)	706	0.4450738
5.	BOD (mg/l)	270	-0.9028417

Value of $Y_S^* = -844.6448$

$$Y_S = -(3.2 \times 1.641028) + (1875 \times 0.0867657) - (6.5 \times 113.7843)$$
$$+ (706 \times 0.4450738) - (270 \times 0.9028417)$$
$$= -5.25 + 162.69 - 739.60 + 314.22 - 243.77$$
$$= -511.70$$

$-511.70 > -844.6448$ i.e. $Y_S > Y_S^*$, hence unsuitable.

The above results can thus be represented as

$$H_U A_N W_U C_U S_U$$

This evaluation indicates the unsuitability of Kanpur wastewater on all the aspects of farming.

Recommendations:

Based on these results the further treatment required to improve its biological quality and means to reduce its salt

contents (since both these parameters seem to be contributing largely towards its unsuitability) may be suggested.

But before any such treatment process is planned, either the present discharge from industries should be stopped flowing into the municipal sewers or it must be treated individually before letting it flow with the rest of domestic sewage.

5. SUMMARY AND CONCLUSIONS

A survey of the status of sewage farming in 8 representative cities was carried out and data collected for formation of a wastewater quality index for sewage farming. Based on the data collected and information from literature, different parameters affecting different aspects of using sewage for irrigation were selected. These aspects are health of farm workers, health of human/animal consumers of farm produce, crops and soil.

Before the formulation of an accumulative index ($\bar{Y}$), separate indices for all the aspects mentioned above are developed. Each such index (represented as Y) would indicate the suitability or otherwise of any wastewater for its corresponding aspect. This intermediate evaluation helped in identifying the problematic parameters in a wastewater. The accumulative quality index ($\bar{Y}$) was then calculated by taking a weighted mean of different values of Y's, which would differ from wastewater to wastewater.

Wastewaters of the surveyed cities were classified as suitable or unsuitable on the basis of the formulated index ($\bar{Y}$). Degree and type of treatments were suggested for those wastewaters which were classified as unsuitable. These suggestions were made on identifying the exact areas of unsuitability as indicated by the individual index value, Y.

Thus based on the findings of this study following conclusions may be drawn:

8. Careful planning and efficient scientific management help a great deal for the effective running of a sewage farm.
9. The effects of wastewater characteristics on soils and plant growth not only depend on their concentration but are also related to the frequency and amount of irrigation water applied.

6. ENGINEERING SIGNIFICANCE & SUGGESTIONS FOR FUTURE WORK

6.1. Engineering Significance:

The hazards associated with raw sewage farming have well been recognized. The present emphasis on recovery of resources and re-use of materials does not let the planners condone this practice, altogether. An optimal approach, therefore, is to eliminate these hazards by pre-treatment of sewage and recover numerous micro and macro-nutrients, it contains, by growing plants. The decision on the degree of pre-treatment based on quantification of parameters affecting adversely shall prove to be more effective.

A measure derived in the form of an index under the present study which can both identify and quantify the negative factors of the wastewater quality, may prove to be a valuable tool for the planners in the field of environmental engineering.

The use of the suggested methodology for development of a specific-use wastewater quality index may also enable the development of appropriate wastewater quality standards for its use in sewage farming.

6.2. Suggestions for Future Work:

Based on the results of this study, it is felt that further work should be pursued in the following areas:

1. The scope of this study which was restricted to domestic waste, can further be widened to include industrial waste also; since complete avoidance of untreated industrial wastewaters being discharged into municipal sewers may be difficult in the near future.

2. Sensitivity of the index values developed in this study can be tested by carrying out some field studies and modified, if required, to satisfy local conditions.
3. Selection of variables for the formation of index in this study, was based on the data collected and information from literature. A future study may be carried out for the same purpose by including more variables and reducing them to a lesser number by principal components, nor correlated to one another.

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APPENDIX A. DISCRIMINANT ANALYSIS

Discriminant analysis is carried under the assumption that the measurements for each group are distributed normally with the same covariance matrices. The procedure is to find a linear combination of the measures (X_1 and X_2) such that the distributions for the two groups will possess "little" overlap. Let the linear discriminant function be

$$Y_{ij} = \beta_1 X_{i1j} + \beta_2 X_{i2j} + \beta_3 X_{i3j} + \cdots + \beta_p X_{ipj}$$

$$i = 1, 2, \ldots, m$$

$$j = 1, 2, \ldots, n_i \qquad \text{(A.1)}$$

where X_{ikj} represents the value of the kth variable for the jth item in the ith group.

β_{is}'s are unknown co-efficients

Subscript i represents the groups, and

ubscript j refers to the item number of the observation within a group.

The co-efficients β's may be evaluated by maximizing the following ratio.

$$= \frac{\text{Between-group variation}}{\text{Within-group variation}} \qquad \text{(A.2)}$$

Let mean vectors of the distributions be represented by the elation

$$\mu_{Y_i} = \beta_1 \mu_{X_{i1}} + \beta_2 \mu_{X_{i2}} + \cdots + \beta_p \mu_{X_{ip}} \qquad \text{(A.3)}$$

$$i = 1, 2, \ldots, m$$

where the values $\mu_{X_{ik}}$ represent the means for the kth variables in the ith group.

Equation (A.3) must hold by definition since the variable Y is a linear combination of the X variables. Using the results of equations (A.1) and (A.3) we find that the deviation of any Y_{ij} about its mean μ_{Y_i} can be written as

$$Y_{ij} - \mu_{Y_i} = \beta_1(X_{i1j} - \mu_{X_{i1}}) + \beta_2(X_{i2j} - \mu_{X_{i2}}) + \ldots + \beta_p(X_{ipj} - \mu_{X_{ip}})$$

$$i = 1, 2, \ldots, m.$$
$$j = 1, 2, \ldots, n_i$$

Thus the sum of squares of $Y_{ij} - \mu_{Y_i}$ will give us a measure of within group variation for the Y variable.

For the sample we replace all population means with sample means

$$\overline{Y}_i = \sum_{j=1}^{n_i} Y_{ij}/n_i, \qquad i = 1, 2, \ldots, m$$

and all population means for the X variables with

$$\overline{X}_{ik} = \sum_{j=1}^{n_i} X_{ikj}/n_i, \qquad i = 1, 2, \ldots, m$$
$$k = 1, 2, \ldots, p$$

Accordingly, for the sample, within-group variation is given by

$$\sum_{i=1}^{m}\sum_{j=1}^{n_i}(Y_{ij} - \overline{Y}_i)^2 = \sum_{i=1}^{m}\sum_{j=1}^{n_i}[\beta_1(X_{i1j} - \overline{X}_{i1}) + \beta_2(X_{i2j} - \overline{X}_{i2}) + \ldots + \beta_p(X_{ipj} - \overline{X}_{ip})]^2$$

This can be written as

$$\sum_{i=1}^{m} \sum_{j=1}^{n_i} (Y_{ij} - \bar{Y}_i)^2 = \underset{\sim}{\beta}' x_1' x_1 \underset{\sim}{\beta} + \underset{\sim}{\beta}' x_2' x_2 \underset{\sim}{\beta}$$

$$= \underset{\sim}{\beta}' \, [(n_1 + n_2 - 2) S_*] \underset{\sim}{\beta}$$

where $x_1'x_1$ and $x_2'x_2$ are the sample covariance matrices,

$$\underset{\sim}{\beta} = (\beta_1, \beta_2, \ldots, \beta_p)$$

and

$$S_* = \frac{x_1'x_1 + x_2'x_2}{n_1 + n_2 - 2}$$

Similarly between-group variation may be expressed, for the sample, as $(\bar{Y}_1 - \bar{Y}_2)^2$ or in matrix notation as

$$\underset{\sim}{\beta}' \, (\bar{X}_1 - \bar{X}_2)(\bar{X}_1 - \bar{X}_2)' \underset{\sim}{\beta}$$

where $\bar{X}_1$ and $\bar{X}_2$ are the matrices of sample means for the two groups, respectively.

Thus the function we wish to maximize attains the form

$$= \frac{1}{n_1 + n_2 - 2} \; \frac{\underset{\sim}{\beta}'(\bar{X}_1 - \bar{X}_2)(\bar{X}_1 - \bar{X}_2)'\underset{\sim}{\beta}}{\underset{\sim}{\beta}' \, S_* \, \underset{\sim}{\beta}}$$

which when maximized gives us the estimates of the co-efficients β's as

$$\hat{\underset{\sim}{\beta}} = S_*^{-1} \, (\bar{X}_1 - \bar{X}_2)$$

The discrimination function can thus be within as

$$Y = \hat{\underset{\sim}{\beta}} \, X'$$

It can be shown that if the costs of misclassification are equal for the two groups and if the probability that an

observation comes from the two groups is equal, then the discriminant plane (Y^*) will lie midway between the two planes (Y_1 and Y_2). Hence the critical value discriminating an object to belong to one or the other group is given by

$$Y^* = \frac{1}{2} \hat{\underset{\sim}{\beta}}' (\overline{X}_1 + \overline{X}_2)$$

The rule for discrimination can now be expressed in the following manner under the assumptions that we have made

Classify as group 1 if $Y_{ij} > Y^*$

Classify as group 2 if $Y_{ij} < Y^*$